N61165.AR.004235
CNC CHARLESTON
5090.3a

CORRECTIVE MEASURES STUDY WORK PLAN ENHANCED IN SITU BIODEGRADATION PILOT TEST FOR SOLID WASTE MANAGEMENT UNIT 39 (SWMU 39) ZONE A CNC CHARLESTON SC

1/1/2001

CH2M HILL

CORRECTIVE MEASURES STUDY WORK PLAN

Enhanced In Situ Biodegradation Pilot Test for SWMU 39, Zone A

Charleston Naval Complex
North Charleston, South Carolina

SUBMITTED TO
U.S. Navy Southern Division
Naval Facilities Engineering Command

PREPARED BY
CH2M-Jones

January 2001

Revision 1
Contract N62467-99-C-0960

CORRECTIVE MEASURES STUDY WORK PLAN

Enhanced In Situ Biodegradation Pilot Test for SWMU 39, Zone A

Charleston Naval Complex
North Charleston, South Carolina

SUBMITTED TO
U.S. Navy Southern Division
Naval Facilities Engineering Command

PREPARED BY
CH2M-Jones

E102000003GNV

January 2001
158814.ZA.PR.01

Revision 1
Contract N62467-99-C-0960

Certification Page for Corrective Measures Study Work Plan – SWMU 39, Zone A

Enhanced In Situ Biodegradation Pilot Test

I, Dean Williamson, certify that this report has been prepared under my direct supervision. The data and information are, to the best of my knowledge, accurate and correct, and the report has been prepared in accordance with current standards of practice for engineering.

South Carolina

Temporary Permit No. T2000342

Dean Williamson, P.E.

1/19/2001

Date

SOUTH CAROLINA
CH2M
HILL, INC.
No. C00201
CERTIFICATE OF AUTHORIZATION

Contents

Acronyms and Abbreviations

BCT	BRAC Cleanup Team
BRAC	Base Realignment and Closure
CA	Corrective Action
CMS	Corrective Measures Study
CNC	Charleston Naval Complex
DCE	cis/trans-1,2-dichloroethene
DOT	Department of Transportation
DPT	Direct-Push Technology
EnSafe	EnSafe, Inc.
EPA	U.S. Environmental Protection Agency
ft bls	feet below land surface
GWMP	Groundwater Monitoring Plan
H_2	molecular hydrogen
HAZWOPER	Hazardous Waste Operations and Emergency Response
HRC	Hydrogen Release Compound
HSWA	Hazardous and Solid Waste Amendments
IDW	Investigation-Derived Waste
µg/L	micrograms per liter
MCL	Maximum Contaminant Level
MNA	Monitored Natural Attenuation
NAVBASE	Naval Base
NAVFACENGCOM	Southern Division Naval Facilities Engineering Command
O&M	Operations and Maintenance
PCE	tetrachloroethene
POL	petroleum, oil, and lubricant
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SCDHEC	South Carolina Department of Health and Environmental Control

1	SOP	Standard Operating Procedure
2	SWMU	Solid Waste Management Unit
3	TCE	trichloroethene
4	UIC	Underground Injection Control
5	VC	vinyl chloride
6	VOC	volatile organic compound

SECTION 1.0

Introduction and Purpose

1.0 Introduction and Purpose

In 1993, Naval Base (NAVBASE) Charleston was added to the list of bases scheduled for closure as part of the Defense Base Realignment and Closure (BRAC) Act, which regulates closure and transition of property to the community. The Charleston Naval Complex (CNC) was formed as a result of the dis-establishment of the Charleston Naval Shipyard and NAVBASE on April 1, 1996.

CNC Corrective Action (CA) activities are being conducted under the Resource Conservation and Recovery Act (RCRA); the South Carolina Department of Health and Environmental Control (SCDHEC) is the lead agency for CA activities at the site. All RCRA CA activities are performed in accordance with the Final Permit (Permit No. SC0 170 022 560).

In April 2000, CH2M-Jones was awarded a contract to provide environmental investigation and remediation services at the CNC. This submittal has been prepared by CH2M-Jones to document the basis for a Corrective Measures Study (CMS)/Pilot Test Work Plan at Solid Waste Management Unit (SWMU) 39 in Zone A at the CNC facility.

1.1 Introduction

CH2M-Jones has prepared this CMS Work Plan on behalf of the Southern Division Naval Facilities Engineering Command (NAVFACENGCOM) to comply with the RCRA Hazardous and Solid Waste Amendments (HSWA) Permit requirements for closure of the CNC facility.

This Pilot Test Work Plan presents the scope of work for the enhanced in situ bioremediation of chlorinated solvents present in groundwater at SWMU 39 in Zone A at the CNC. Natural bioremediation processes will be enhanced by the injection of Hydrogen Release Compound® (HRC®) into the aquifer at selected locations.

1.2 Purpose

The general purpose of this Pilot Test is to determine the effectiveness of enhanced bioremediation of chlorinated solvent contamination in groundwater by injecting HRC into the subsurface and allowing it to permeate into the aquifer. An additional specific objective of the study is to reduce concentrations of chlorinated volatile organic

compounds (VOCs) in SWMU 39 area groundwater below applicable maximum contaminant levels (MCLs) by treating potential source areas of chlorinated VOCs in groundwater. If this study indicates that HRC injection is feasible for aquifer remediation, it will be added to the upcoming CMS alternatives analysis for consideration as a final remedy.

This Pilot Test Work Plan presents a description of the SWMU 39 study area, a summary of the extent of VOC groundwater contamination, a description of the HRC technology and the technical approach to be used, methods for monitoring HRC effectiveness, and a proposed implementation schedule.

1.3 Organization of the CMS Pilot Test Work Plan

This CMS Work Plan consists of the following eight sections, including this introductory section:

1.0 Introduction —Presents the purpose of and background information on the work plan.

2.0 SWMU 39 Site Description —Provides a site description of the SWMU 39 study area, including a summary of the extent of contamination and site hydrogeologic conditions.

3.0 Remedial Objectives —Discusses the overall remedial objectives at SWMU 39, including the rationale and evaluation process for testing in situ groundwater contaminant plume control via HRC injection.

4.0 HRC® Technology Description —Presents information on the properties and applications of HRC technology.

5.0 Pilot Study Technical Approach and Methodology —Presents the proposed HRC injection approach at three test sites, the field methods to be employed to place the HRC, proposed new monitor well locations, and the analytical parameter list to be used for monitoring of the aquifer before, during, and after the test.

6.0 Project Schedule —Presents the proposed schedule for implementation of field work and for submission of project deliverables.

7.0 Investigation-Derived Waste —Discusses the methods to be used for handling soil cuttings, development water, and other wastes generated as part of this test.

8.0 References —Lists the references used in this document.

Appendix A contains the typical groundwater elevation contours for shallow, intermediate, and deep aquifer zones.

Appendix B contains the HRC® Technology Information Package.

Appendix C contains geologic cross sections and structural contours.

Appendix D contains responses to SCDHEC comments.

All tables and figures appear at the end of their respective sections.

SECTION 2.0

SWMU 39 Site Description

2.0 SWMU 39 Site Description

SWMU 39 is the site of a former outdoor storage area for petroleum, oil, and lubricant (POL) drums along the north wall of Building 1604. Building 1604 is a large warehouse building located near the northern boundary of the CNC. SWMU 39 is bounded to the north by the Hess Oil tank farm, to the west by a road and railroad along the base boundary, to the south by railroad lines and buildings associated with SWMU 42, and to the east by buildings associated with SWMU 38 (see Figure 2-1).

A marine equipment company currently leases Building 1604 and stores boats and other marine equipment outdoors, north of the building. The original area where drums were presumably stored is now covered with asphalt pavement.

2.1 Current Nature and Extent of Contamination

The SWMU 39 area was previously studied by EnSafe, Inc. (EnSafe) during the Zone A RCRA Facility Investigation (RFI) completed in 1998 (EnSafe 1998), and a Monitored Natural Attenuation (MNA) study was completed in 1999. The results of the MNA study were reported in a CMS Technical Memorandum (EnSafe 1999). Extensive soil and groundwater investigations were conducted, revealing fairly widespread but diffuse occurrence of chlorinated VOCs in the shallow, intermediate, and deep zones of the unconfined shallow (water table) aquifer.

No significant areas of chlorinated VOC soil contamination were identified at SWMU 39 that could be acting as a continuing groundwater contamination source. The most commonly occurring constituents in groundwater include tetrachloroethene (PCE), trichloroethene (TCE), cis/trans-1,2-dichloroethene (DCE), and vinyl chloride (VC). Chlorinated VOC concentrations have been observed to be somewhat variable and, in many cases, to have decreased during subsequent groundwater monitoring events. This trend was confirmed during the most current groundwater monitoring event, conducted by CH2M-Jones in July 2000 for the facility-wide Groundwater Monitoring Plan (GWMP). This information is presented in Table 2-1. However, the current groundwater VOC concentrations continue to exceed applicable primary drinking water standards, requiring some type of corrective action.

During the RFI, maximum chlorinated VOC concentrations observed were in the 100 - 300 microgram per liter (µg/L) range in monitor well clusters A039GW012 and A039GW013. Well cluster A039GW012 is located directly south of Building 1604; well cluster A039GW013 is located approximately 400 feet to the south, on the south side of Building 1607 (see Figure 2-2).

The most recent water quality data collected during CH2M-Jones's July 2000 groundwater monitoring field effort included results from well cluster A039GW013 and from new monitor well cluster A039GW023, which was recently installed to fill a data gap along the western CNC boundary. Analytical results are presented in Table 2-1. Well cluster A039GW023 is located approximately 600 feet southwest of Building 1604 (see Figure 2-2). These recent data indicate that chlorinated VOC concentrations have decreased to less than 100 µg/L at monitor well cluster A039GW013 and that significant quantities of reductive dechlorination daughter product compounds such as DCE and VC are being produced at this location. At well A039GW023D, chlorinated VOC compounds are now being detected in the 5 - 20 µg/L range, indicating either a diffuse local source or the arrival of the leading edge of the dissolved VOC groundwater plume originating from the interior of the SWMU 39 area.

Both of these aquifer conditions can be effectively treated by injection of HRC, and the exact conditions under which the VOCs were introduced is not critical to the success of the Pilot Test.

2.2 Hydrogeology Overview and Contaminant Fate and Transport Summary

The site hydrogeology consists of a series of Quaternary interbedded sands and clays, varying in thickness from 21 to 56 feet in the SWMU 39 area. The sands and clays contain an unconfined (water table) aquifer system that overlies the Tertiary Ashley Formation. The Ashley Formation is comprised of silts and clays and acts as an aquiclude for the water table aquifer. Monitor wells are installed in shallow, intermediate, and deep sandy zones of groundwater flow in the water table aquifer. The three zones are interconnected and converge into one hydrogeologic unit south of Building 1607. Appendix A presents typical groundwater elevation contours for the shallow, intermediate, and deep aquifer zones.

The shallow groundwater flow direction has been consistently determined to be in a generally southerly direction, with a separate flow component to the southwest, toward

an offsite wetland area. There is minimal tidal influence on groundwater levels, and flow velocities averaging 14 feet per year have been calculated by EnSafe, based on aquifer testing results.

Based on available historic site maps, Building 1604 and nearby buildings were built in the 1943-1947 time frame. Using a conservative assumption that POL storage and releases occurred from the first day of operations, groundwater from SWMU 39 could have migrated up to approximately 800 feet downgradient by the present date. This is a worst case distance that assumes no biodegradation or adsorption of VOCs.

The EnSafe Monitored Natural Attenuation Study (EnSafe 1999) reported that aquifer conditions conducive to natural bioremediation of chlorinated VOCs by reductive chlorination processes vary in the SWMU 39 vicinity. The conditions required generally become more favorable moving southward, but still may not be optimal for complete dechlorination of VOCs. The groundwater quality data support the conclusion that natural bioremediation of chlorinated VOCs is occurring to some degree, but degradation rates could be increased and more complete dechlorination achieved by adding an organic substrate such as HRC.

TABLE 2-1
SWMU 39 Selected Groundwater Sampling Results — July 2000
CMS Work Plan Pilot Test, Charleston Naval Complex Zone A, SWMU 39

Well ID	Analyte	Result (µg/L)	Lab Qualifier
A039G0013	1,1-dichloroethene	0.58	J
A039G0013	1,1-dichloroethane	1.3	J
A039G0013	Methylene chloride (dichloromethane)	1.9	J
A039G0013	Cis/tTrans-1,2-dichloroethene	44	=
A039G0013	Tetrachloroethene	7	=
A039G0013	Trichloroethene	2.9	J
A039G013I	1,1-dichloroethene	4.2	J
A039G013I	Benzene	0.84	J
A039G013I	1,1-dichloroethane	7.2	=
A039G013I	Methylene chloride (dichloromethane)	1.3	J
A039G013I	Vinyl chloride	25	=
A039G013I	Tetrachloroethene	83	=
A039G013I	Trichloroethene	51	=
A039G013D	1,1-dichloroethene	5	=
A039G013D	Benzene	1.1	J
A039G013D	1,1-dichloroethane	3.8	J
A039G013D	Methylene chloride (dichloromethane)	1.3	J
A039G013D	1,1,2-trichloroethane	5	=
A039G013D	Vinyl chloride	12	=
A039G013D	Tetrachloroethene	63	=
A039G013D	Trichloroethene	88	=
A039G0023	Methylene chloride (dichloromethane)	18	=
A039G0023	Acetone	13	=
A039G0023	Trichloroethene	0.45	J
A039G0023	Phenol	0.62	J
A039G023D	Methylene chloride (dichloromethane)	18	=
A039G023D	Vinyl chloride	4.9	J
A039G023D	Cis/Trans-1,2-dichloroethene	15	=
A039G023D	Tetrachloroethene	27	=
A039G023D	Trichloroethene	20	=

Notes:

= The compound was detected at the indicated value.
J Indicates that the compound was not detected and the concentration is an estimated value.

Units of measurement are in µg/L.

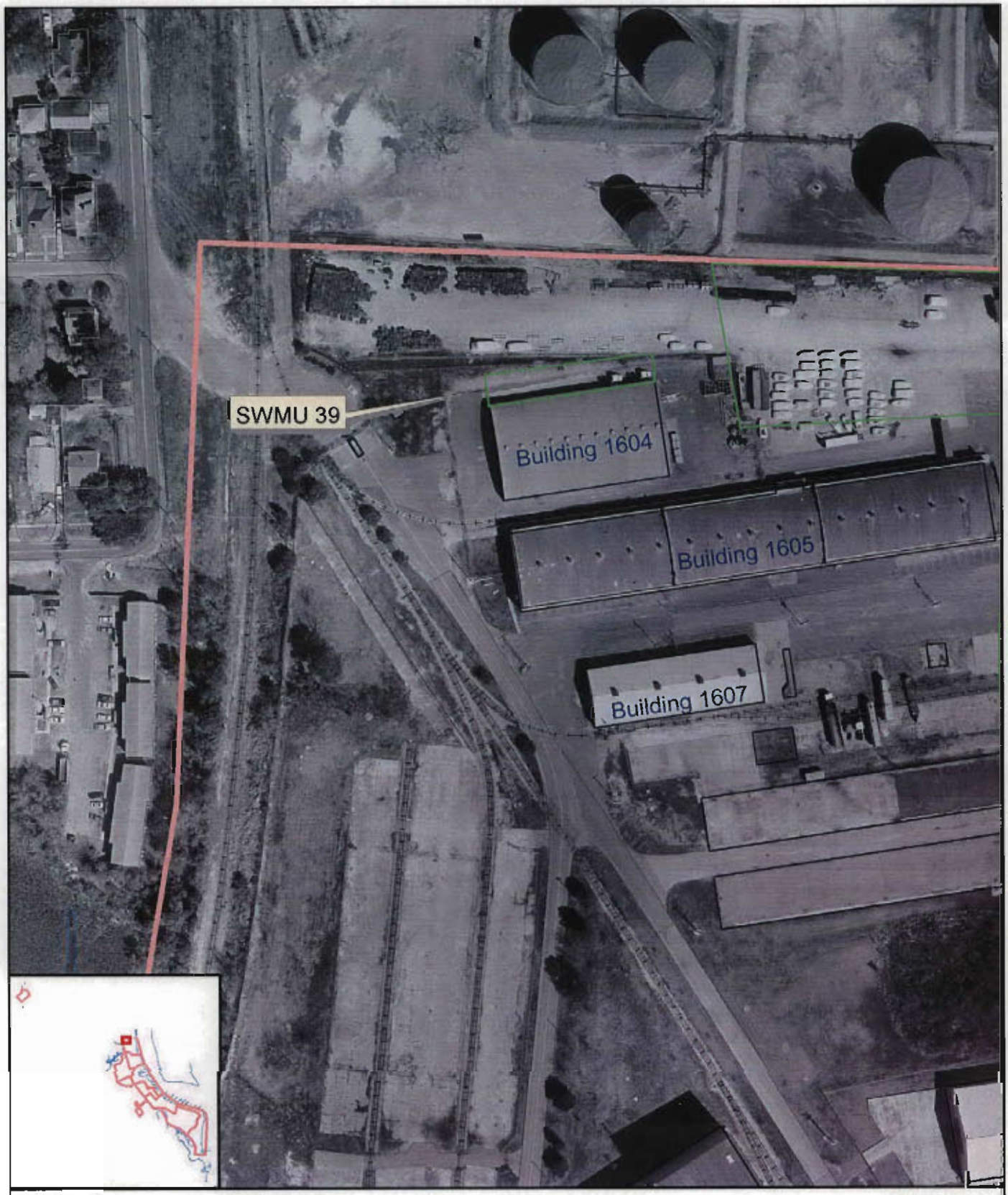


Figure 2-1
Site Location Map
Zone A - SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

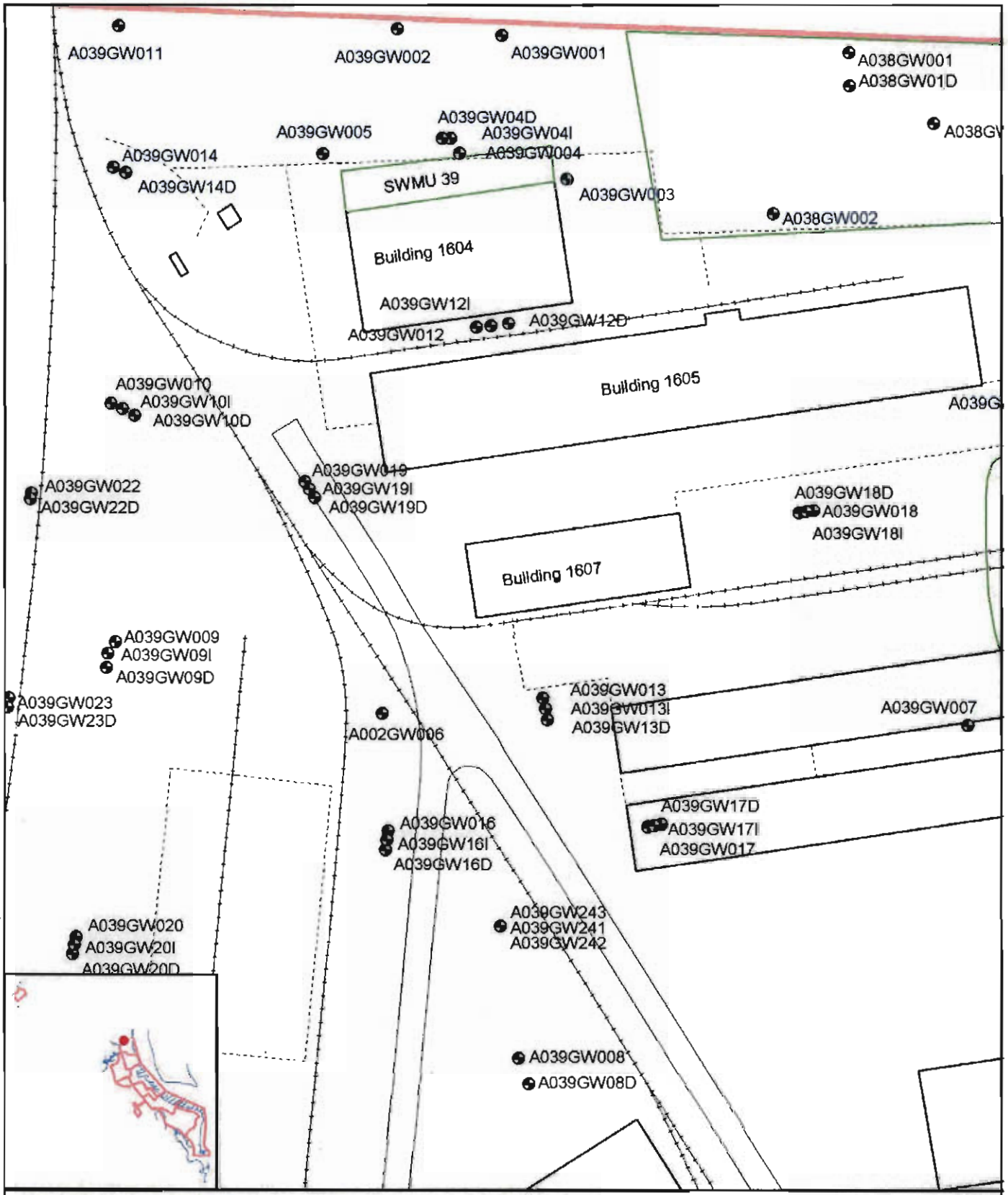


Figure 2-2
Monitor Well Locations
Zone A - SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

SECTION 3.0

Remedial Objectives

3.0 Remedial Objectives

This section discusses the dual objectives of this pilot test, these being the control of contaminated groundwater and the evaluation of HRC injection as a remedial alternative at NAVBASE Charleston.

3.1 Groundwater Contaminant Source Control

The HRC pilot study is intended to evaluate the potential for an enhanced in situ bioremediation approach to function as a chlorinated VOC groundwater source reduction/source control mechanism at SWMU 39. Because no discrete VOC sources were identified in soils during the RFI, dissolved phase VOC groundwater plume treatment is expected to be the primary remedial action required to reduce VOC concentrations in groundwater to acceptable risk levels for site closure. An additional objective is to assess the effectiveness of enhanced in situ biodegradation to act as a contaminant plume control cutoff method in the vicinity of well A039GW023D.

Conventional technologies such as groundwater pumping and treatment are not likely to be highly feasible or cost-effective due to low-flow aquifer characteristics and high initial and Operations and Maintenance (O&M) expense relative to perceived benefit. Because some of the buildings are still used, a passive in situ technology such as enhanced bioremediation with HRC injection is desirable as a low-disturbance alternative.

The chlorinated VOCs in groundwater can be biologically degraded by naturally occurring microorganisms. When chlorinated VOCs are naturally degraded under anaerobic conditions, the process is termed "reductive dechlorination." The microbes substitute a hydrogen atom for a chlorine atom on the chlorinated VOC molecule, thereby reducing the chlorination state of the compound. This process often occurs naturally at a rate too slow to be sustained as a viable remedial approach for a final remedy (ITRC 1999). Addition of a suitable organic substrate such as HRC to the aquifer can increase the rate of dechlorination by one order of magnitude or more, ultimately producing a non-toxic ethene end-product (Regenesis 2000).

3.2 HRC® Technology Evaluation

The HRC pilot study will determine the effectiveness of enhanced reductive dechlorination as a groundwater bioremediation strategy for SWMU 39. Technology issues to be evaluated during this study include the following:

- Methods of introduction into the aquifer
- Required density of injection points per unit of aquifer area
- Amount of HRC required to create measurable enhancement of natural reductive dechlorination rates
- Effective life of HRC after injection
- Frequency of injections required to achieve the desired reduction through post-injection monitoring

SECTION 4.0

HRC® Technology Description

4.0 HRC® Technology Description

This section describes the properties of HRC, which enhance natural bioremediation of chlorinated VOCs in groundwater, and the general injection process typically used to introduce the HRC into the aquifer system. The HRC proposed for injection at SWMU 39 is a product of Regenesis Bioremediation Products, Inc. The technology has been applied at more than 70 field sites across the U.S., and the effectiveness of the technology has been documented by quantitative field demonstrations in numerous publications, including the proceedings of Battelle-sponsored conferences. The properties of HRC and the application mechanism are summarized below, and a technical information package is presented in Appendix B, discussing the HRC technology in detail. Available information also includes a website address (www.regenesis.com), where additional case studies and technology development information can be reviewed.

4.1 HRC Properties

HRC is a proprietary, environmentally safe, food-grade polylactate ester liquid that releases lactic acid when in contact with groundwater under reducing conditions. The indigenous microbes metabolize the lactic acid, resulting in the generation of molecular hydrogen (H_2). The H_2 is then used as an electron donor by reductive dechlorination microbes to rapidly dechlorinate the PCE, TCE , DCE, or VC molecules; the chlorinated solvents act as electron acceptors.

Because the hydrogen is slowly and continuously released, a single injection of HRC can continue to work for up to one year. By maintaining a constant low concentration of hydrogen in the aquifer, HRC can optimize dechlorination activity without generating excess potentially hazardous byproducts such as methane, which also impedes complete dechlorination (Regenesis 2000).

4.2 HRC Injection

HRC is typically introduced to the aquifer by a subsurface injection process with the Geoprobe Direct-Push Technology (DPT). A multi-point injection grid is designed based on aquifer characteristics and contaminant concentrations to ensure uniform application of the HRC into the aquifer.

SECTION 5.0

Pilot Study Technical Approach and Methodology

5.0 Pilot Study Technical Approach and Methodology

This section discusses the technical approach and rationale for applying the HRC at three locations, the field methods to be used at each location, and the personnel who will be involved in performing the field work.

5.1 HRC Injection Approach

CH2M-Jones proposes to perform HRC injection and post-injection monitoring at three locations in SWMU 39. In the interior of the dissolved phase VOC plume, the areas immediately adjacent to two 3-well clusters have been selected as HRC injection points: well clusters A039GW012 and A039GW013. At these locations, contaminant plume source control will be attempted, as both well clusters consistently display the highest concentrations of multiple chlorinated VOCs at SWMU 39.

At the leading edge of the southwestern plume component, well cluster A039GW023 (near the western CNC property boundary) has been selected as a plume cutoff case study location. The study intent at this location is installing HRC to create a biologically reactive barrier to intercept and cut off the downgradient contaminant migration. The effectiveness of the treatment will be monitored by periodically sampling selected monitor wells near each injection location after the injection is complete, as well as monitoring groundwater quality at well A039GW023D periodically to assess the downgradient impact of the pilot test on this well.

CH2M-Jones and Regenesis have used available aquifer performance information and groundwater VOC contaminant distribution data to develop injection grids for each of the three proposed injection locations. General injection locations are shown in Figure 5-1. The proposed layout for each injection grid is presented in Figures 5-2, 5-3, and 5-4. Final injection grid size and location will be adjusted in the field, as required by site conditions.

For conceptual purposes, a composite isconcentration diagram depicting dissolved concentrations of PCE, TCE, and 1,2-DCE in groundwater has been added to Figures 5-1 and 5-5. The contours presented represent the approximate limits where these constituents exceed their applicable drinking water MCLs in the shallow aquifer system.

For worst-case analysis, the highest concentration detected in intermediate or deep monitor wells at each cluster location was chosen for mapping. The data used are also temporal composites, using analytical results from both the latest round of groundwater monitoring performed by CH2M-Jones in July 2000, and data from the EnSafe Natural Attenuation Monitoring conducted in August 1999.

5.2 HRC Injection Methodology

Once the appropriate grid layout is established at each site by field measurements, the HRC will be injected at each location using a Geoprobe DPT rig equipped with 1.25-inch outside diameter threaded drill rods. The HRC will be pumped from clean plastic containers through an application hose and injected down through the drill rods using a specially designed pump recommended by Regenesis. The HRC will be placed along the entire saturated aquifer thickness at an application rate of approximately 2 to 4 pounds of HRC per vertical foot, as discussed in the text that follows.

The injection grid adjacent to existing monitor well cluster A039GW012 will be a 20-foot by 40-foot rectangle, surrounding the well cluster, with 9 injection locations, as shown in Figure 5-2. At each location, a separate injection will be performed in the shallow, intermediate, and deep aquifer zones, due to the heterogeneous subsurface geology in this area. This technique will yield a total of 27 Geoprobe injection points. At this grid, HRC will also be injected at a higher rate (4 pounds per vertical foot) due to the heterogeneous geology.

At the A039GW013 well cluster location, the injection grid will be approximately a 30-foot by 30-foot square with 9 injection locations, as shown in Figure 5-3. At each location, HRC will be injected into the intermediate and deep zone depths using a separate Geoprobe boring, yielding a total of 18 Geoprobe points. HRC will be injected here at a rate of 2 pounds per vertical foot.

At existing well cluster A039GW023, the final injection grid dimensions and location will be determined in the field, based upon lithologic and analytical results obtained from a series of 10 Geoprobe borings to a depth of 50 feet. The Geoprobe borings are intended to determine the width of the southwestern VOC groundwater plume component which is affecting well cluster A039GW023. The borings will be installed in a straight line paralleling and east of the railroad, spaced at 20-foot intervals, as shown in Figure 5-4. Groundwater samples will be recovered from the lower part of the aquifer at each Geoprobe boring location and analyzed for VOCs using a rapid turnaround

laboratory. Because VOC contamination at well cluster A039GW023 is greatest in the lowest portion of the aquifer, sampling the lowest aquifer portion is approriate to find the VOC plume in this area. The HRC injection grid will then be positioned as close to the center of the plume as possible, to treat the area where VOC concentrations are highest. It is estimated that approximately 9 Geoprobe locations will be used to inject HRC into the intermediate and deep intervals, yielding a total of 18 Geoprobe points.

A Hazardous Waste Operations and Emergency Response (HAZWOPER)-trained Geoprobe vendor with HRC injection experience will be contracted for the HRC injection work, and will supply the proper equipment and personnel for reaching depths of up to 50 feet below land surface (ft bls). Field work will be supervised by a CH2M-Jones site hydrogeologist or field engineer. Regenesis personnel will also be on site to supervise grid layout and HRC injection operations.

CH2M-Jones will also coordinate with SCDHEC personnel to meet necessary Underground Injection Control (UIC) Permit requirements found in South Carolina's Underground Injection Control Regulation (R.61-87).

5.3 Monitor Well Installation

Six new monitor wells will be installed in three well pairs, consisting of an intermediate depth well and a deep well at each location:

- One intermediate/deep well pair (A039GW25I and A039GW25D) will be installed near existing monitor well cluster A039GW023 and the HRC injection grid at that location, to assist in monitoring HRC effectiveness at the leading edge of the VOC plume (downgradient plume at boundary).
- One intermediate/deep well pair (A039GW26I and A039GW26D) will be installed near the south wall of Building 1605, south of existing well cluster A039GW012 (downgradient-plume interior).
- One intermediate/deep well pair (A039GW27I and A039GW27D) will be installed near the west wall of Building 1607 (downgradient-plume interior).

Two of the six new wells, designated A039GW25I and A039GW25D, will be installed to monitor HRC effectiveness near well cluster A039GW23. The four remaining new wells (A039GW26I, A039GW26D, A03927I, and A03927D) are being installed to provide additional water quality, water level, and stratigraphic data in the interior of the plume area, and are not intended to monitor HRC effectiveness during the Pilot Test.

Proposed locations for these new monitor wells are shown in Figure 5-5.

The wells will be installed by a HAZWOPER-trained drilling vendor, under the direct supervision of the CH2M-Jones site hydrogeologist. Well borings will be advanced using appropriate drilling techniques.

The deepest ("D") well boring in each new cluster will be lithologically logged to assist in well screen placement and to refine the site hydrogeologic conceptual model. The drill rig, tools, and equipment will be properly decontaminated between borings using the procedures described in the approved EnSafe sampling and analysis portion of the EnSafe *Final Comprehensive Sampling and Analysis Plan, Volume II* (July 30, 1996). Protocols for sampling and sample handling will also comply with requirements of EPA Environmental Services Division *Environmental Investigations Standard Operating Procedures and Quality Assurance Manual* (EPA 1996).

The wells will be constructed of 2-inch inside diameter flush-threaded Schedule 40 polyvinyl chloride (PVC) with screen lengths of 10 feet. New well installation depths will be comparable to those of the existing monitor wells in the shallow aquifer. Approximate total depths for intermediate wells will be 20 to 30 ft bls; depths for new deep wells will be approximately 40 to 50 feet. Exact depths will be determined in the field, based on the lithologic log recovered during each boring.

The wells will be installed, developed, and sampled for aquifer geochemical baseline and VOC parameters prior to initiating the actual HRC injections. Monitor well borings, well installation, development, and sampling will be performed in accordance with the Field Sampling Plan (EnSafe 1995). Selected CH2M-Jones Standard Operating Procedures (SOPs) for field work in U.S. Environmental Protection Agency (EPA) Region IV will also be referenced and utilized as necessary to address updates in applicable technologies and procedures.

Appropriate permits and approvals will be obtained from SCDHEC for all temporary DPT points and permanent well locations, in accordance with South Carolina Well Standards and Regulations (R.61-71), prior to mobilizing for the field effort.

Abandonment of Geoprobe borings after sampling or HRC injection will also be accomplished in accordance with applicable SCDHEC regulations and guidance.

5.4 Measurement of Baseline Geochemical and Post-Injection Parameters

A groundwater sampling event will be performed before HRC injection for initial (pre-injection) baseline monitoring of geochemical natural attenuation parameters using the nearby existing monitor wells and the new wells installed during this study. A geochemical groundwater monitoring event will also be performed approximately two months after the HRC injections. These analytical results will be compared to the baseline results to confirm that HRC is creating the necessary changes in aquifer reducing conditions to induce reductive dechlorination near the well clusters.

If geochemical data indicate that lactic acid hydrolysis and hydrogen release are occurring in the aquifer, a VOC groundwater quality sampling event will be performed using existing and new monitor wells to begin charting the dechlorination process. The VOC groundwater sampling will be performed at least three more times at three-month intervals to verify and document the rate of dechlorination and degradation product ratios.

Chemical analysis of groundwater samples will be conducted using EPA SW-846 Methods for RCRA monitoring. The proposed analytical parameter lists for monitoring aquifer geochemical conditions and VOC contaminant distribution during this pilot test are presented in Tables 5-1, 5-2, and 5-3. Tables 5-1, 5-2, and 5-3 show the analytical parameter list and type of monitoring to be performed for selected wells at well clusters A039GW12, A039GW13, and A039GW23, respectively. Table 5-4 presents the analytical list for new wells within the plume interior, away from the HRC Pilot Test locations.

Response rates of native microbes to the addition of an artificial substrate are site-specific. For this reason, it is difficult to predict the precise amount of time required for the microbes to acclimate to the presence of increased levels of lactic acid in the aquifer. Experience at other sites indicates that this response and acclimation phase may take from 2 to 6 months. The ongoing natural reductive dechlorination indicates the presence of favorable microbes at the site. Because CNC has a temperate climate, the acclimation phase is expected to be at the lower end of this range, and enhancement of reductive dechlorination may occur within 2 to 4 months.

If the groundwater data collected during the initial 6 months does not indicate an increased response, CH2M-Jones will discuss the feasibility of continuing or stopping the pilot test with the BRAC Cleanup Team (BCT). Alternatively, if the process appears

suitably effective, CH2M-Jones will also consider extending and continuing the HRC process at this site.

5.5 HRC Performance Verification Monitoring

As discussed in Section 5.4, periodic geochemical and VOC performance verification monitoring will be performed throughout the pilot test to determine the effectiveness of the HRC treatment on the aquifer. The well clusters nearest each injection point will be sampled to verify the effect of HRC on the aquifer at known contaminant source strength locations.

An initial sampling event with analysis for only the geochemical parameters listed in Table 5-1 will be conducted approximately one week prior to injection. These parameters are key indicators of the types and rates of biological activity necessary to effectively utilize the HRC for dechlorination. Wells proposed for geochemical baseline sampling at each injection location, and the proposed analytical parameter list, are presented in Tables 5-1, 5-2, and 5-3.

A second geochemical sampling event and analysis will be conducted approximately two months after the injections occur to evaluate whether sufficient changes in aquifer geochemistry have occurred to indicate that enhanced reductive dechlorination is occurring.

When geochemical results indicate conditions are favorable for dechlorination, groundwater samples will be collected for VOC analysis to monitor degradation compound generation and parent compound dechlorination rates. Wells proposed for performance verification sampling at each injection location, and the proposed analytical parameter list, are presented in Tables 5-1, 5-2, and 5-3.

The VOC performance verification monitoring will be performed at least three more times at 3-month intervals to continue documenting the effectiveness and duration of the HRC treatment.

Water levels will be measured in all SWMU 39 area wells during each sampling event to provide additional potentiometric data. The potentiometric data will be used to refine the site hydrogeologic model and to document the groundwater flow conditions during the pilot test. All well sampling will be performed in accordance with the approved EnSafe FSP and CH2M-Jones SOPs, as appropriate. Chemical analysis of groundwater samples will be conducted using EPA SW-846 Methods for RCRA monitoring.

TABLE 5-1
Proposed HRC Pilot Test Groundwater Monitoring Parameters at Well Cluster A039GW012 Location
CMS Work Plan Pilot Test, Charleston Naval Complex Zone A, SWMU 39

Analytical Parameter	Analysis Method	Baseline Monitoring[a]			Post-Injection Geochemical Monitoring[b]			Periodic Performance Monitoring[c]		
Monitor Well Number		*A039GW012*	*A039GW12I*	*A039GW12D*	*A039GW012*	*A039GW12I*	*A039GW12D*	*A039GW012*	*A039GW12I*	*A039GW12D*
Geochemical Parameters										
Alkalinity, Total	EPA 310.1	X	X	X	X	X	X			
Chloride	SM 4500C1-B	X	X	X	X	X	X			
Nitrate/Nitrite	EPA 353.3	X	X	X	X	X	X			
Organic Carbon, Total	EPA 5310 B	X	X	X	X	X	X	X	X	X
Sulfate	EPA 375.4	X	X	X	X	X	X			
Sulfide	EPA 376.2	X	X	X	X	X	X			
pH	Field	X	X	X	X	X	X	X	X	X
Conductivity	Field	X	X	X	X	X	X	X	X	X
Oxidation-Reduction Potential	Field	X	X	X	X	X	X	X	X	X
Temperature	Field	X	X	X	X	X	X	X	X	X
Dissolved Gases										
Methane/Carbon Dioxide	ASTM D1945	X	X	X	X	X	X	X	X	X
Ethane	ASTM D1945	X	X	X	X	X	X	X	X	X
Ethene	ASTM D1945	X	X	X	X	X	X	X	X	X
Hydrogen	ASTM D1945	X	X	X	X	X	X	X	X	X
Oxygen	Field	X	X	X	X	X	X	X	X	X
Volatile Organic Acids										
Acetic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Butyric Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Lactic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Propionic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Pyruvic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Dissolved Metals										
Iron II and III (filtered)	EPA 200.7	X	X	X	X	X	X	X	X	X
Manganese (filtered)	EPA 200.7	X	X	X	X	X	X	X	X	X
Volatile Organic Compounds										
Tetrachloroethene	SW 8260B/ 624	X	X	X				X	X	X
Trichloroethene	SW 8260B/ 624	X	X	X				X	X	X
Cis-1,2-dichloroethene	SW 8260B/ 624	X	X	X				X	X	X
Trans-1,2-dichloroethene	SW 8260B/ 624	X	X	X				X	X	X
1,1-dichloroethene	SW 8260B/ 624	X	X	X				X	X	X
Vinyl chloride	SW 8260B/ 624	X	X	X				X	X	X

[a]Approximately one month prior to HRC injection.
[b]At an elapsed time of approximately two months after HRC injection.
[c]Three events occurring every three months, beginning one month after post-injection geochemical monitoring occurs.
X = every event

TABLE 5-2
Proposed HRC Pilot Test Groundwater Monitoring Parameters at Well Cluster A039GW013 Location
CMS Work Plan Pilot Test, Charleston Naval Complex Zone A, SWMU 39

Analytical Parameter	Analysis Method	Baseline Monitoring[a]			Post-Injection Geochemical Monitoring[b]			Periodic Performance Monitoring[c]		
Monitor Well Number		*A039GW013*	*A039GW13I*	*A039GW13D*	*A039GW013*	*A039GW13I*	*A039GW13D*	*A039GW013*	*A039GW13I*	*A039GW13D*
Geochemical Parameters										
Alkalinity, Total	EPA 310.1	X	X	X	X	X	X	X	X	X
Chloride	SM 4500C1-B	X	X	X	X	X	X	X	X	X
Nitrate/Nitrite	EPA 353.3	X	X	X	X	X	X	X	X	X
Organic Carbon, Total	EPA 5310 B	X	X	X	X	X	X	X	X	X
Sulfate	EPA 375.4	X	X	X	X	X	X	X	X	X
Sulfide	EPA 376.2	X	X	X	X	X	X	X	X	X
pH	Field	X	X	X	X	X	X	X	X	X
Conductivity	Field	X	X	X	X	X	X	X	X	X
Oxidation-Reduction Potential	Field	X	X	X	X	X	X	X	X	X
Temperature	Field	X	X	X	X	X	X	X	X	X
Dissolved Gases										
Methane/Carbon Dioxide	ASTM D1945	X	X	X	X	X	X	X	X	X
Ethane	ASTM D1945	X	X	X	X	X	X	X	X	X
Ethene	ASTM D1945	X	X	X	X	X	X	X	X	X
Hydrogen	ASTM D1945	X	X	X	X	X	X	X	X	X
Oxygen	Field	X	X	X	X	X	X	X	X	X
Volatile Organic Acids										
Acetic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Butyric Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Lactic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Propionic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Pyruvic Acid	HPLC/UV	X	X	X	X	X	X	X	X	X
Dissolved Metals										
Iron II and III (filtered)	EPA 200.7	X	X	X	X	X	X	X	X	X
Manganese (filtered)	EPA 200.7	X	X	X	X	X	X	X	X	X
Volatile Organic Compounds										
Tetrachloroethene	SW 8260B/ 624	X	X	X				X	X	X
Trichloroethene	SW 8260B/ 624	X	X	X				X	X	X
Cis-1,2-dichloroethene	SW 8260B/ 624	X	X	X				X	X	X
Trans-1,2-dichloroethene	SW 8260B/ 624	X	X	X				X	X	X
1,1-dichloroethene	SW 8260B/ 624	X	X	X				X	X	X
Vinyl chloride	SW 8260B/ 624	X	X	X				X	X	X

[a]Approximately one month prior to HRC injection.
[b]At an elapsed time of approximately two months after HRC injection.
[c]Three events occurring every three months, beginning one month after post-injection geochemical monitoring occurs.
X = every event

TABLE 5-3
Proposed HRC Pilot Test Groundwater Monitoring Parameters at Well Cluster A039GW023 Location
CMS Work Plan Pilot Test, Charleston Naval Complex Zone A, SWMU 39

Analytical Parameter	Analysis Method	Baseline Monitoring[a]		Post-Injection Geochemical Monitoring[b]		Periodic Performance Monitoring[c]			
Monitor Well Number		NEW WELL A039GW25I	NEW WELL A039GW25D	NEW WELL A039GW25I	NEW WELL A039GW25D	NEW WELL A039GW25I	NEW WELL A039GW25D	A039GW023	A039GW23D
Geochemical Parameters									
Alkalinity, Total	EPA 310.1	X	X	X	X				
Chloride	SM 4500C1-B	X	X	X	X				
Nitrate/Nitrite	EPA 353.3	X	X	X	X				
Organic Carbon, Total	EPA 5310 B	X	X	X	X	X	X		
Sulfate	EPA 375.4	X	X	X	X				
Sulfide	EPA 376.2	X	X	X	X				
pH	Field	X	X	X	X	X	X	O	O
Conductivity	Field	X	X	X	X	X	X	O	O
Oxidation-Reduction Potential	Field	X	X	X	X	X	X	O	O
Temperature	Field	X	X	X	X	X	X	O	O
Dissolved Gases									
Methane/Carbon Dioxide	ASTM D1945	X	X	X	X	X	X	O	O
Ethane	ASTM D1945	X	X	X	X	X	X	O	O
Ethene	ASTM D1945	X	X	X	X	X	X	O	O
Hydrogen	ASTM D1945	X	X	X	X	X	X	O	O
Oxygen	Field	X	X	X	X	X	X	O	O
Volatile Organic Acids									
Acetic Acid	HPLC/UV	X	X	X	X	X	X		
Butyric Acid	HPLC/UV	X	X	X	X	X	X		
Lactic Acid	HPLC/UV	X	X	X	X	X	X		
Propionic Acid	HPLC/UV	X	X	X	X	X	X		
Pyruvic Acid	HPLC/UV	X	X	X	X	X	X		
Dissolved Metals									
Iron II and III (filtered)	EPA 200.7	X	X	X	X				
Manganese (filtered)	EPA 200.7	X	X	X	X				
Volatile Organic Compounds									
Tetrachloroethene	SW 8260B/ 624	X	X			X	X	O	O
Trichloroethene	SW 8260B/ 624	X	X			X	X	O	O
Cis-1,2-dichloroethene	SW 8260B/ 624	X	X			X	X	O	O
Trans-1,2-dichloroethene	SW 8260B/ 624	X	X			X	X	O	O
1,1-dichloroethene	SW 8260B/ 624	X	X			X	X	O	O
Vinyl chloride	SW 8260B/ 624	X	X			X	X	O	O

[a]Approximately one month prior to HRC injection.
[b]At an elapsed time of approximately two months after HRC injection.
[c]Three events occurring every three months, beginning one month after post-injection geochemical monitoring occurs.
X = every event
O = last event only

TABLE 5-4
Proposed HRC Pilot Test Groundwater Monitoring Parameters at New Monitor Wells in Plume Interior
CMS Work Plan Pilot Test, Charleston Naval Complex Zone A, SWMU 39

Analytical Parameter	Analysis Method	Periodic Performance Monitoring[c]			
Monitor Well Number		NEW WELL A039GW26I	NEW WELL A039GW26D	NEW WELL A039GW027I	NEW WELL A039GW27D
Geochemical Parameters					
Alkalinity, Total	EPA 310.1				
Chloride	SM 4500C1-B				
Nitrate/Nitrite	EPA 353.3				
Organic Carbon, Total	EPA 5310 B	X	X		
Sulfate	EPA 375.4				
Sulfide	EPA 376.2				
pH	Field	X	X	X	X
Conductivity	Field	X	X	X	X
Oxidation-Reduction Potential	Field	X	X	X	X
Temperature	Field	X	X	X	X
Volatile Organic Compounds					
Tetrachloroethene	SW 8260B/ 624	X	X	X	X
Trichloroethene	SW 8260B/ 624	X	X	X	X
Cis-1,2-dichloroethene	SW 8260B/ 624	X	X	X	X
Trans-1,2-dichloroethene	SW 8260B/ 624	X	X	X	X
1,1-dichloroethene	SW 8260B/ 624	X	X	X	X
Vinyl chloride	SW 8260B/ 624	X	X	X	X

[a]Three events occurring every three months, beginning one month after post-injection geochemical monitoring occurs.

X = every event

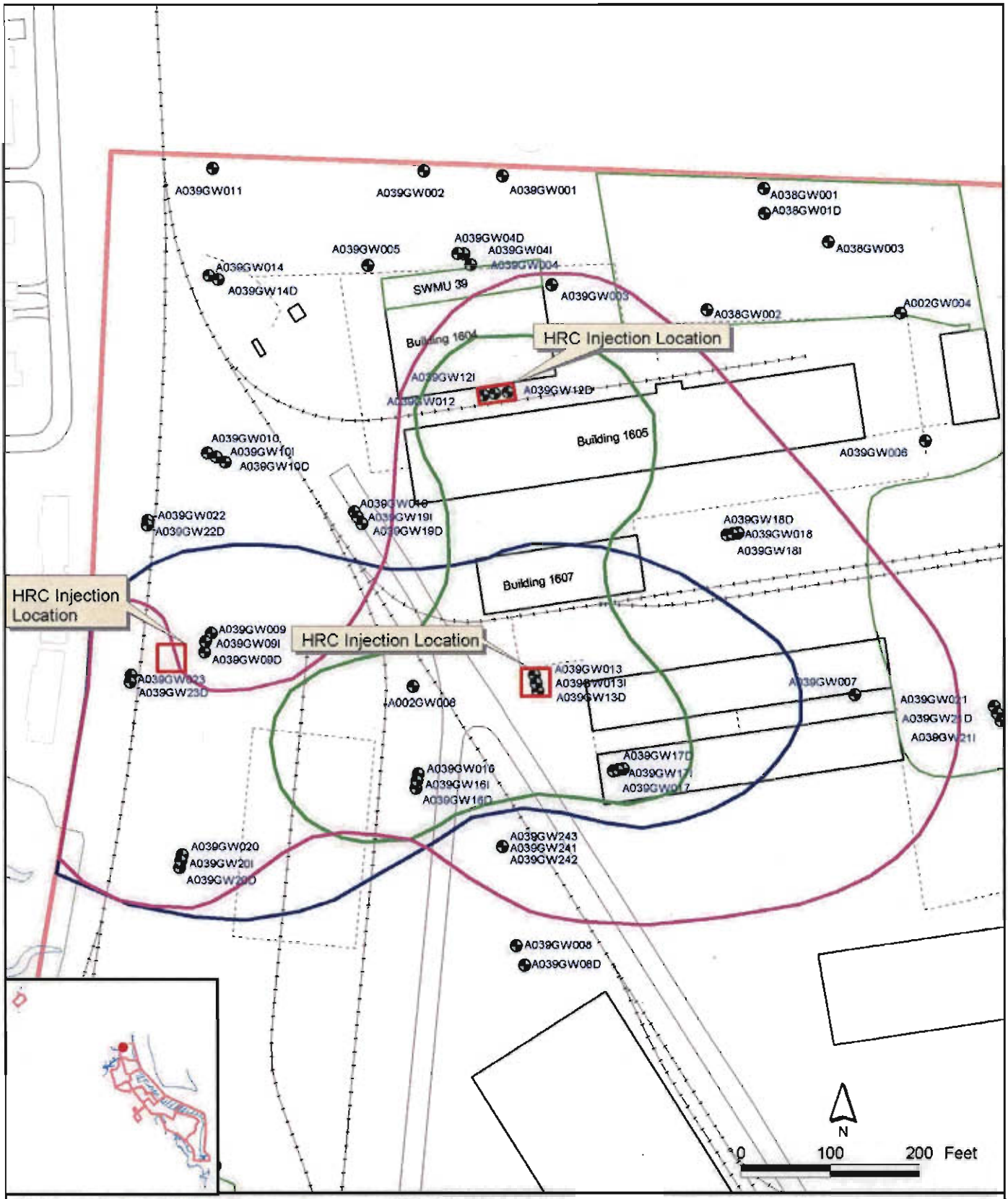


Figure 5-1
Proposed HRC Injection Locations
Zone A - SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

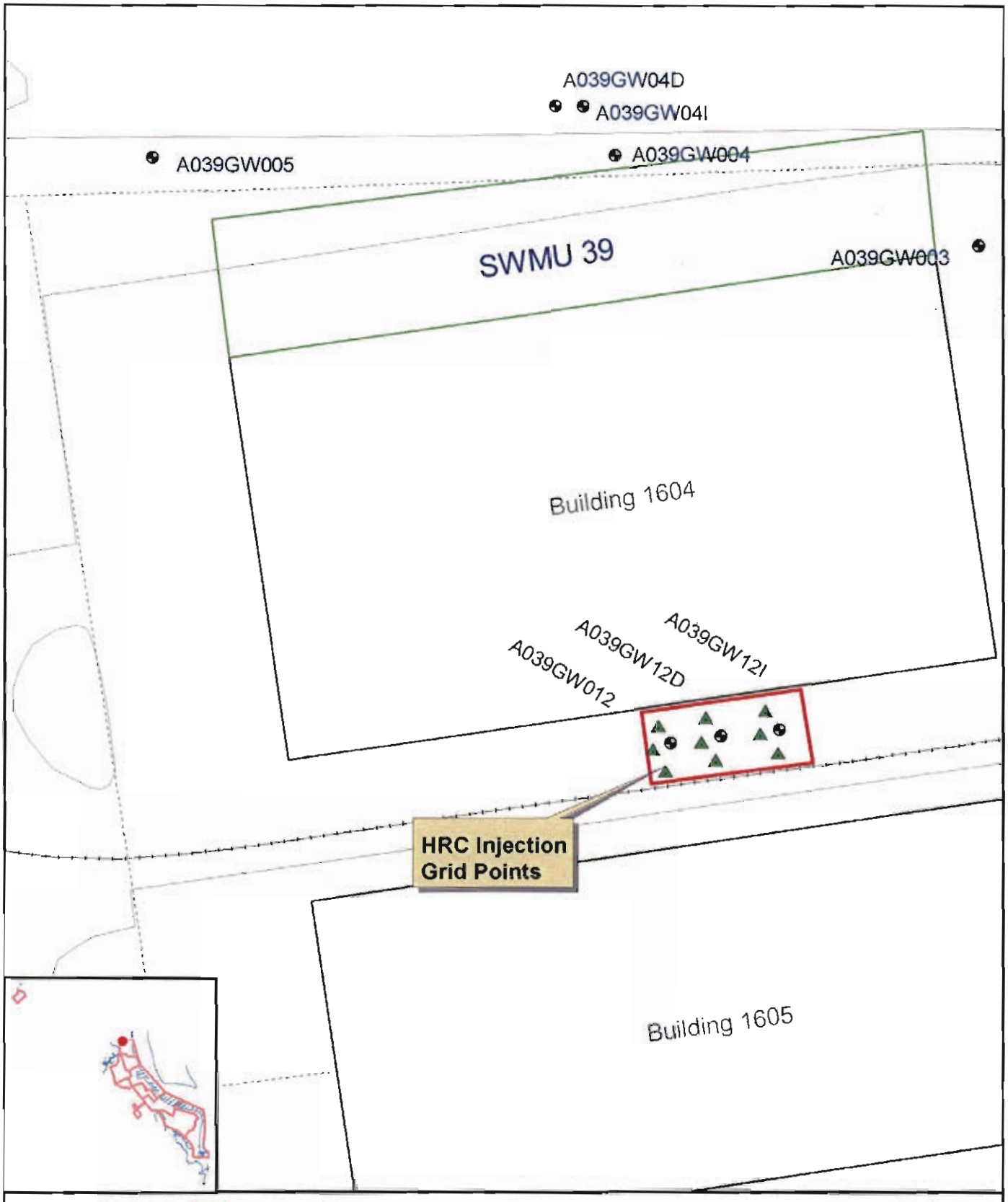


Figure 5-2
A039GW012 Area HRC Injection Grid
Zone A - SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

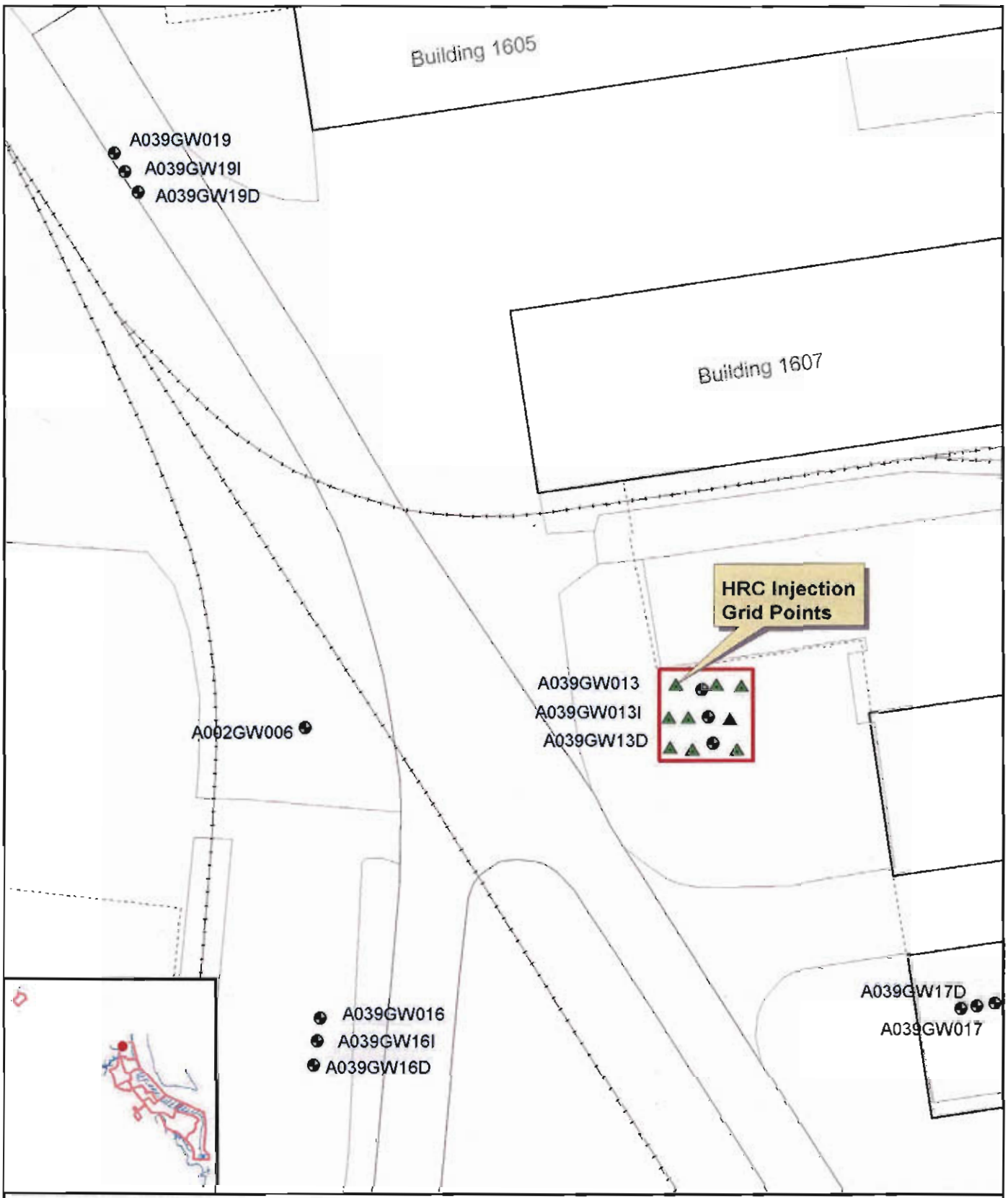


Figure 5-3
A039GW13 Area HRC Injection Grid
Zone A - SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

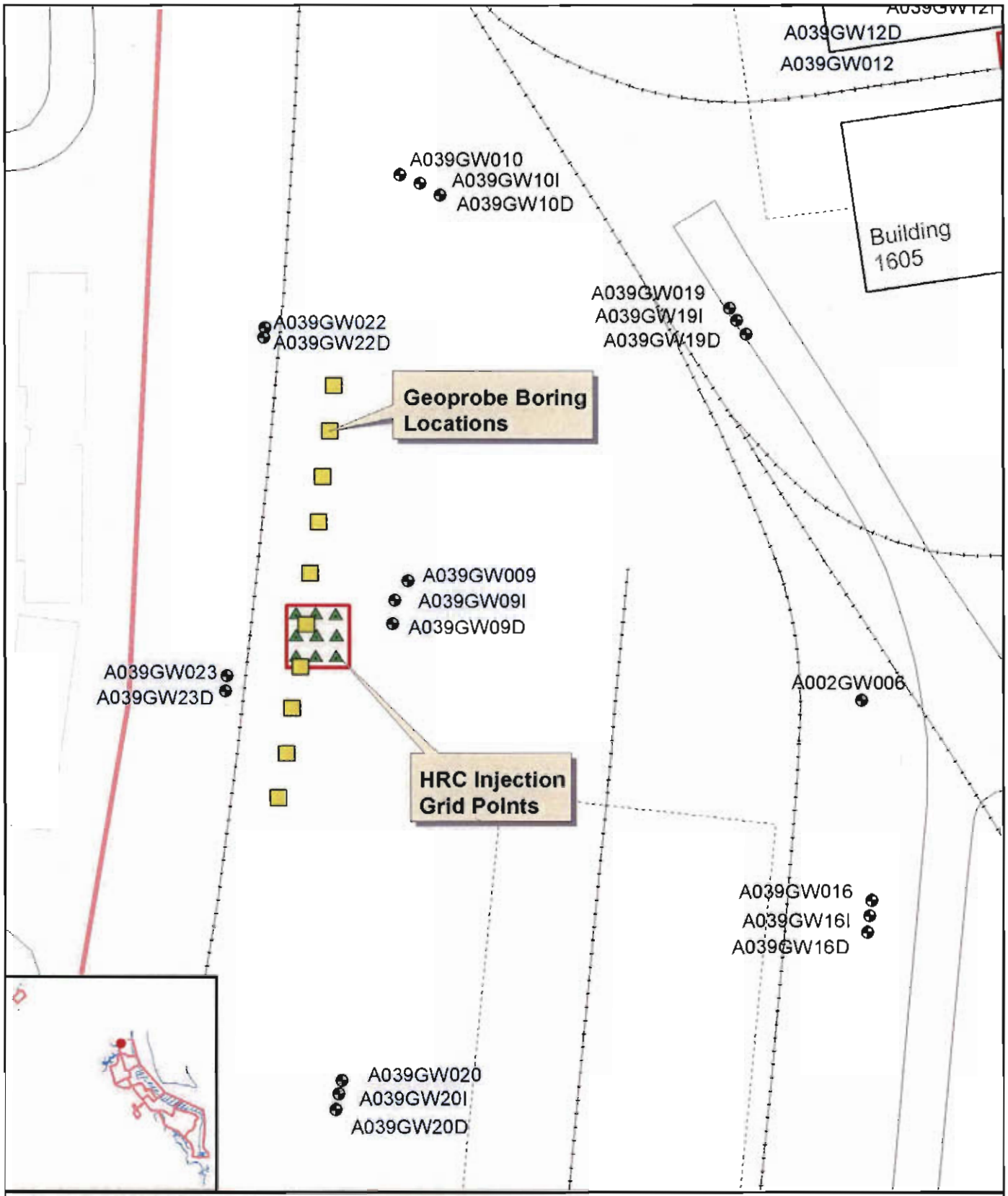


Figure 5-4
A039GW023 Area HRC Injection Grid
Zone A -SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

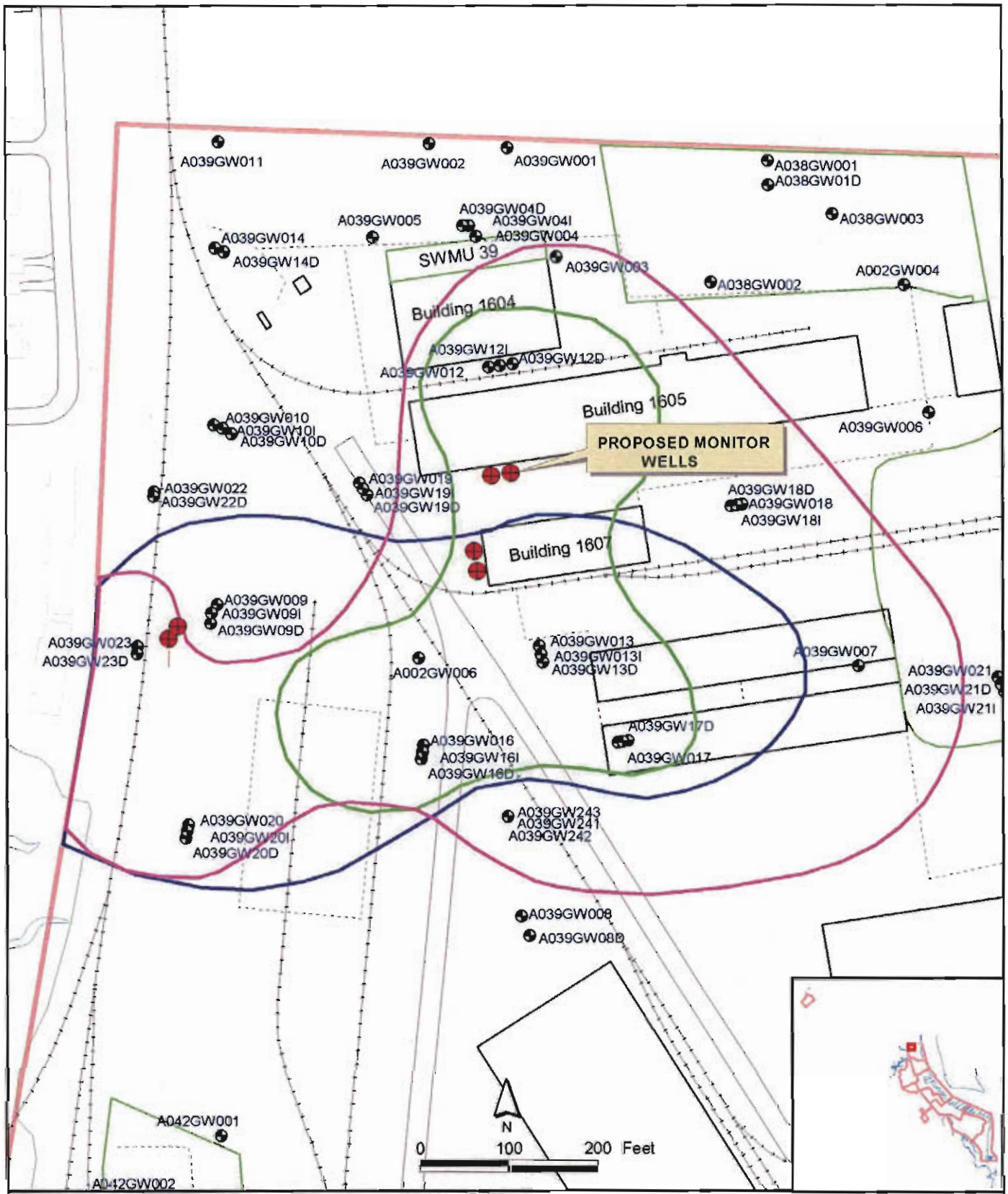


Figure 5-5
Proposed Monitor Well Locations
Zone A - SWMU 39
Charleston Naval Complex

CH2MHILL

E102000003GNV

SECTION 6.0

Project Schedule

6.0 Project Schedule

This section presents a conceptualized schedule for implementation of the pilot test, based on elapsed calendar days after receipt of Final CMS Work Plan approval from SCDHEC.

6.1 Field Work

The field work will be performed in phases and will be initiated within 30 days after Final CMS Work Plan approval. Anticipated milestone tasks are outlined as follows:

- Geoprobe Investigation near AO39GW23—30 days after SCDHEC approval of Work Plan
- New Monitor Well Installation—20 days after completion of Geoprobe investigation
- Injection Grid Layout—during monitor well installation
- Initial Baseline Geochemical Monitoring— 7days after completion of monitor well installation
- Injection of HRC—7 days after completion of baseline geochemical monitoring
- Second Geochemical Monitoring Event —60 days after HRC injection
- First Verification Monitoring Event— 75 days after HRC injection
- Second Verification Monitoring Event—165 days after HRC injection
- Third Verification Monitoring Event—255 days after HRC injection

6.2 Deliverables

The proposed schedule for project deliverables is based on the assumptions made for completion of field work and laboratory analysis. Target dates for key deliverables are summarized below:

- Revision 1 Work Plan/ Response to DHEC Comments—30 days after receipt of SCDHEC comments on Draft Work Plan

- Interim Progress Reports —30 days after receipt of analytical data for each sampling event
- Draft CMS Pilot Test Report —365 days after SCDHEC approval of Work Plan
- Response to SCDHEC comments on Draft CMS Pilot Test Report —30 days after receipt of comments
- Final CMS Pilot Test Report —30 days after comments/responses are finalized

SECTION 7.0

Investigation-Derived Waste Management

7.0 Investigation-Derived Waste Management

During field activities, a certain amount of Investigation-Derived Waste (IDW) will be generated in association with personal protection, Geoprobe borings, monitor well installation and development, and groundwater sampling activities. The majority of the material generated is expected to be uncontaminated or below applicable disposal criteria, because new well installation is occurring downgradient of the SWMU. Every effort will be made to minimize the amount of IDW generated during this work.

At each new well location, soil cuttings and development water will be containerized separately in closed Department of Transportation (DOT) 55-gallon steel drums, staged on pallets near each new well. The drums will each be labeled with the date of generation, type of waste, and associated monitor well identification number. The analytical results obtained for each well will be used to determine the proper disposal option for the associated wastes.

SECTION 8.0

References

8.0 References

EnSafe, Inc. *Final Comprehensive Sampling and Analysis Plan, Volume II.* Revision 2. July 30, 1996.

EnSafe, Inc. *Zone A RCRA Facility Investigation Report, NAVBASE Charleston.* Revision 0. August 7, 1998a.

EnSafe, Inc. *Zone A SWMU 39 Corrective Measures Study Technical Memorandum on Monitored Natural Attenuation Feasibility.* December 22, 1999.

Interstate Technology and Regulatory Cooperation Work Group. *Natural Attenuation of Chlorinated Solvents in Groundwater, Principles and Practice.* May 1999.

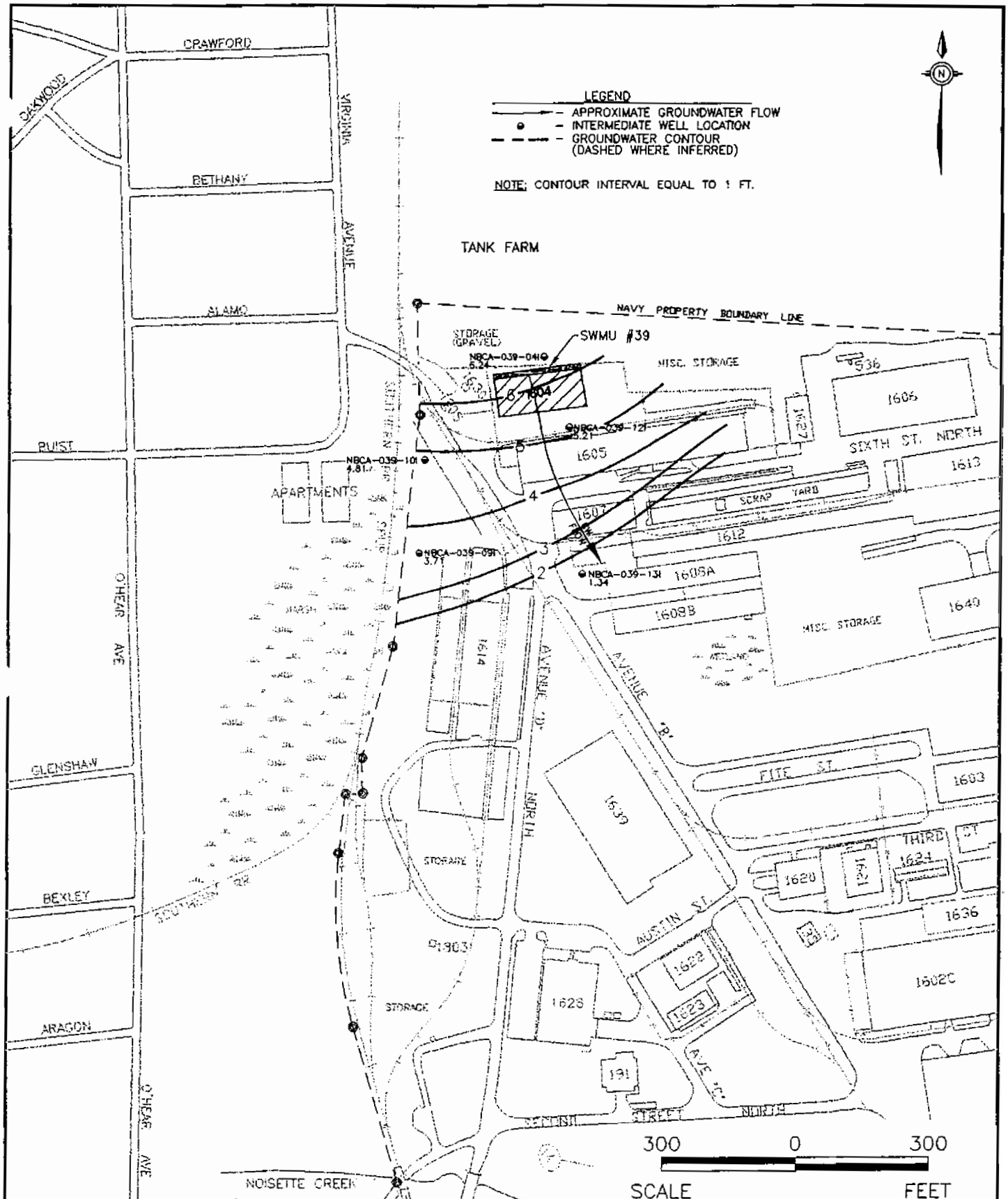
Regenesis Bioremediation Products, *Accelerated Bioremediation of Chlorinated Compounds in Groundwater.* Copyright 2000.

Regenesis Bioremediation Products. *Accelerated Bioremediation Using Slow Release Compounds, Selected Battelle Conference Papers:1993-1999.* Copyright 2000.

U.S. Environmental Protection Agency (EPA), *Environmental Investigations Standard Operating Procedures and Quality Assurance Manual.* Region IV Environmental Services Division. 1996.

APPENDIX A

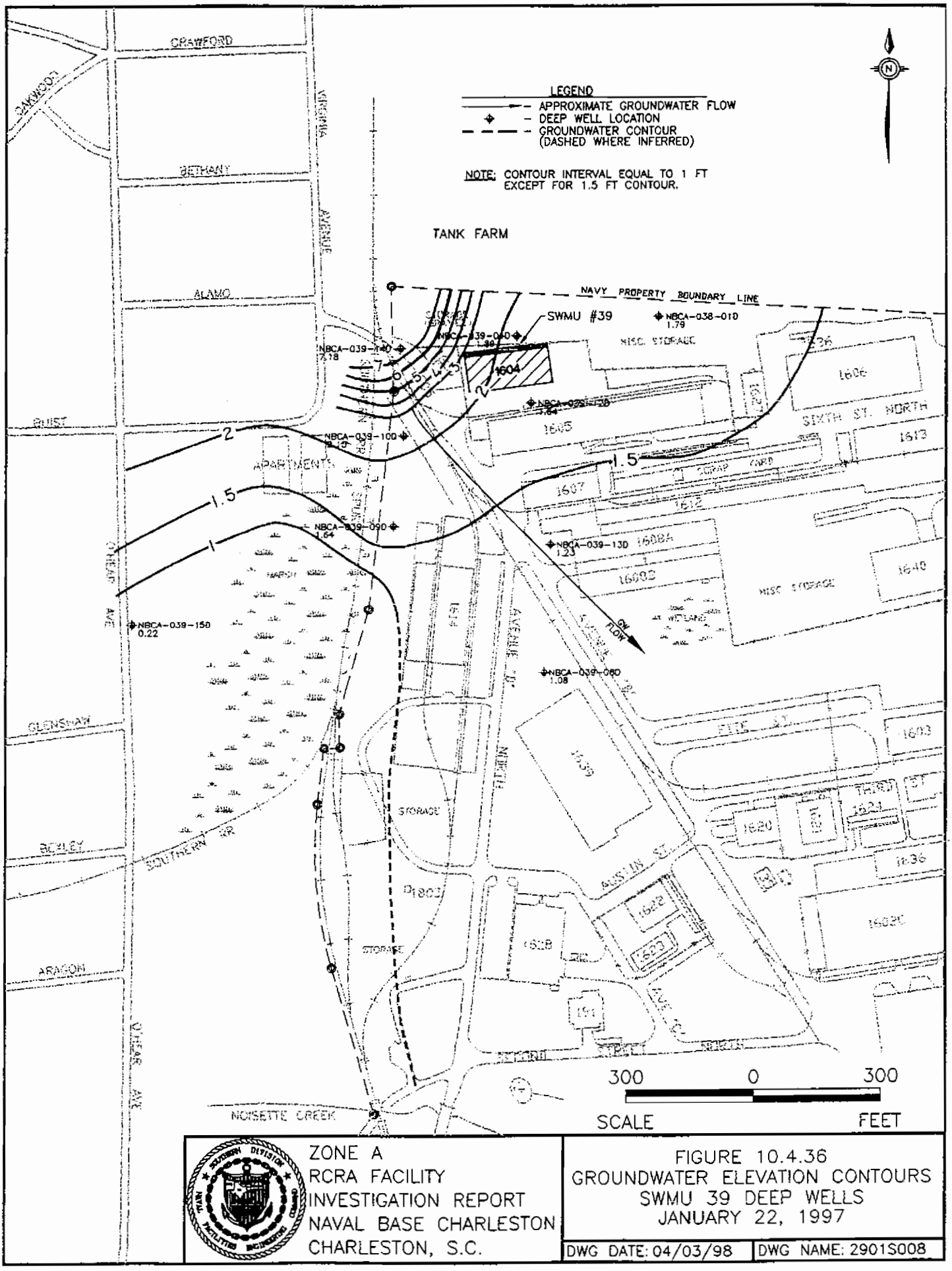
Typical Groundwater Elevation Contours for Shallow, Intermediate, and Deep Aquifer Zones



ZONE A
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 10.4.35
GROUNDWATER ELEVATION CONTOURS
SWMU 39 INTERMEDIATE WELLS
JANUARY 22, 1997

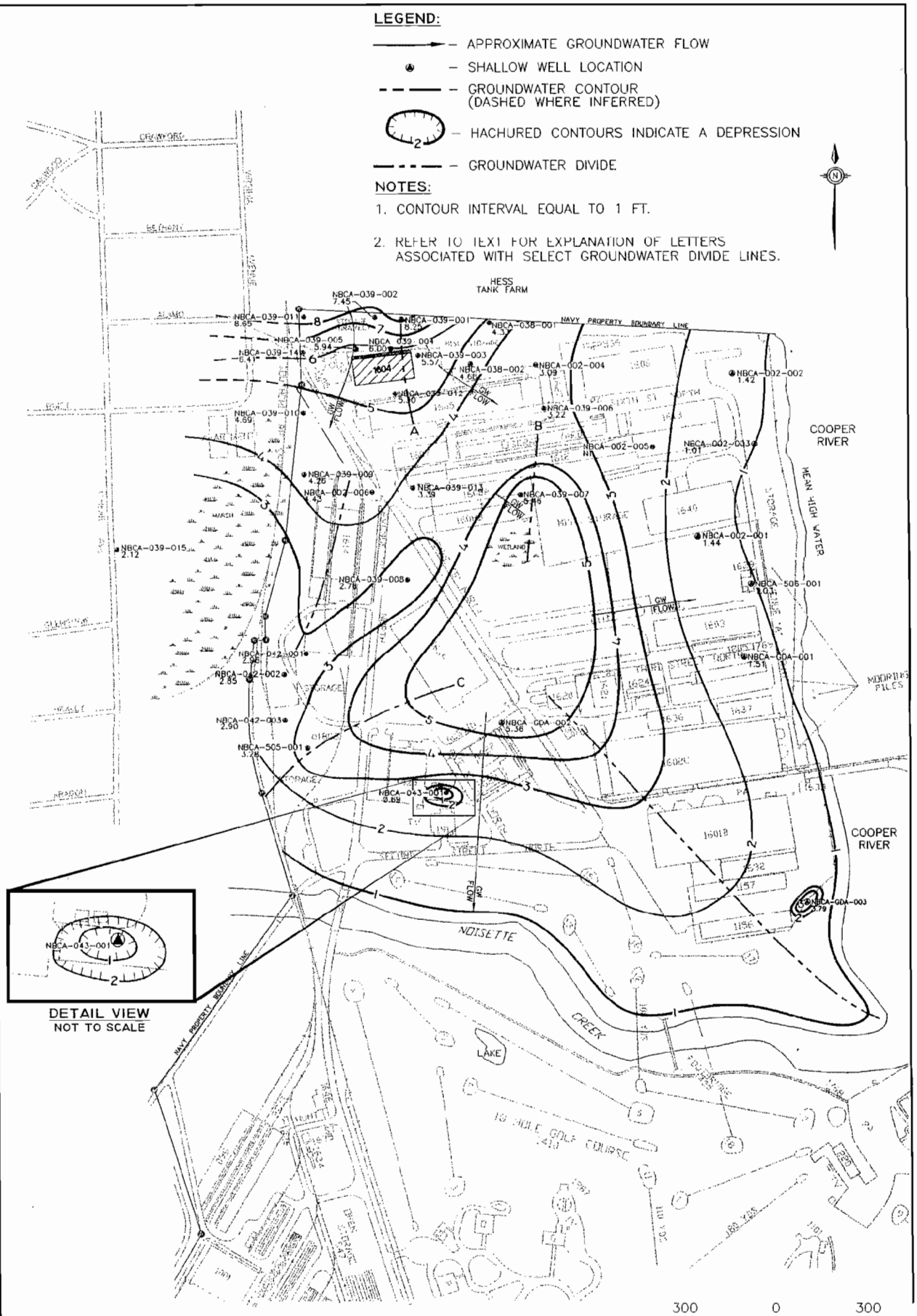
DWG DATE: 04/03/98 | DWG NAME: 2901S007



ZONE A
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 10.4.36
GROUNDWATER ELEVATION CONTOURS
SWMU 39 DEEP WELLS
JANUARY 22, 1997

DWG DATE: 04/03/98 | DWG NAME: 2901S008



ZONE A
RCRA FACILITY
INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.

FIGURE 10.4.34
GROUNDWATER ELEVATION CONTOURS
SWMU 39 SHALLOW WELLS
JANUARY 22, 1997

DWG DATE: 04/03/98 | DWG NAME: 2901S006

APPENDIX B

HRC® Technology Information Package

HRC®: Low Cost Chlorinated Contaminant Treatment

Hydrogen Release Compound (HRC®) offers a passive, low-cost, approach to rapid remediation of chlorinated solvent impacted sites. HRC is a proprietary, environmentally safe polylactate ester specially formulated for slow release of lactic acid upon hydration. When placed within a contaminated aquifer, HRC stimulates a multi-step process resulting in the degradation of chlorinated solvent compounds such as PCE, TCE, TCA and their derivatives, as well as other chlorinated compounds. ***The use of HRC results in the cost-effective and rapid restoration of property values.***

Advantages of HRC & Its Time Release Feature

1. **Low cost:**
   Since HRC is a passive, *in-situ* approach, the large capital and operations/maintenance (O&M) costs associated with active engineered systems are avoided, such as those associated with pump and treat, air sparging with soil vapor extraction, and continuous injection systems. Treatment with HRC is a fraction of the cost of expensive and inflexible "iron wall" technology.

2. **Rapid:**
   HRC produces a continuous, slow release of hydrogen into the contaminated aquifer. This hydrogen serves as an electron donor increasing rates of contaminant degradation by an order of magnitude or more over that of natural attenuation alone.

3. **Degrades PCE and TCE to non-toxic end products:**
   Because of its consistent slow release of hydrogen, HRC stimulates rapid and complete dechlorination resulting in non-toxic end products such as ethene. HRC has also been proven effective in treating a range of other halogenated compounds, perchlorates, pesticides, nitrate and chromium.

4. **Simple and safe to install:**
   HRC is simply added to the bottom of excavations or applied directly into the aquifer through push-points or borings. HRC is a non-toxic, food-grade compound that is safe to install and is environmentally sound.

5. **Cuts off plume migration and eliminates future liability:**
   HRC can be strategically applied to degrade contaminants around the plume's perimeter to avoid further migration. This effective form of "barrier" technology is applied at a fraction of the cost of iron wall technologies or active pumping or sparging systems.

6. **Desorbs and degrades residual DNAPL:**
   Residual DNAPL which is difficult to locate and treat is desorbed and degraded in place by a combination of HRC's stimulation of biosurfactant activity and its continuous production of highly diffusible hydrogen.

7. **Time-release eliminates continuous substrate additions:**
   By providing a constant hydrogen source, HRC dramatically reduces O&M costs compared to the repeated or continuous injections required when attempting a treatment with solutions of common organic substrates.

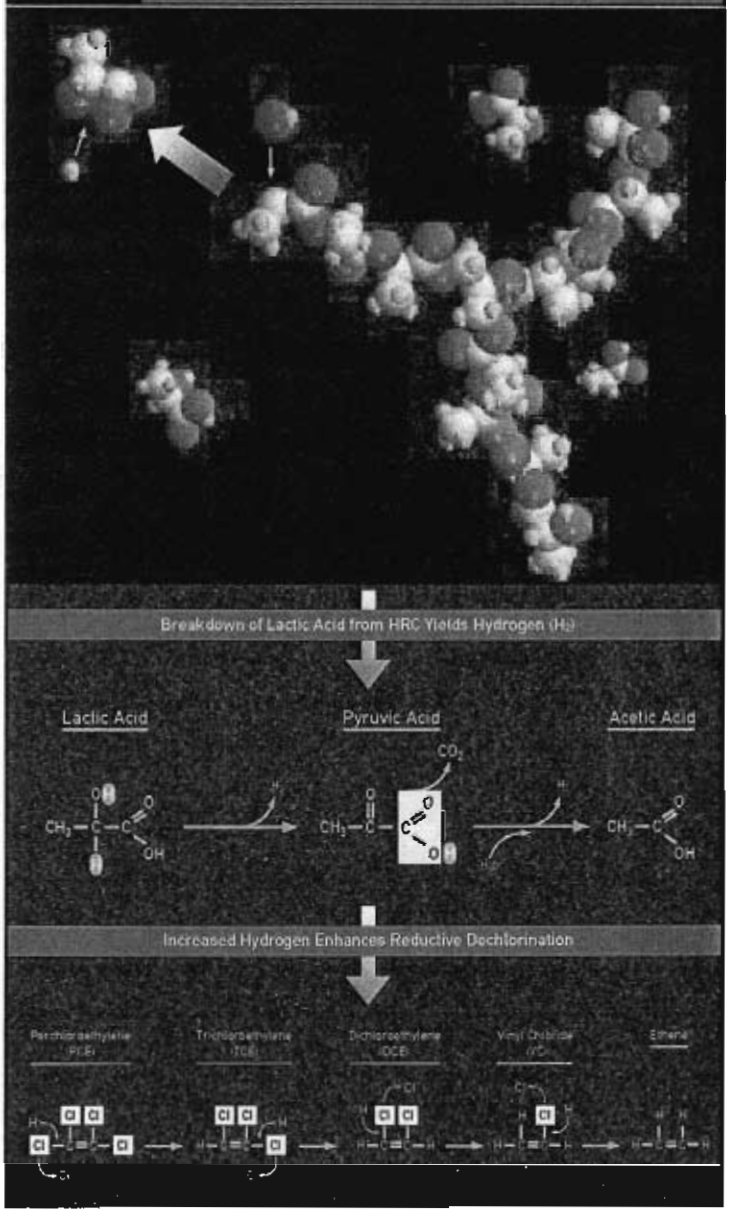
8. **Optimizes dechlorination activity.**
   By maintaining a constant low concentration of hydrogen within the contaminated aquifer, HRC can optimize dechlorination activity. Rapid releases of hydrogen associated with common organic substrate applications result in the wasteful and potentially dangerous generation of methane, interfering with dechlorination activity.

HRC and Reductive Dechlorination

Reductive dechlorination is a term used to describe the mechanism by which chlorinated hydrocarbons are biologically degraded under anaerobic conditions. In this natural process, anaerobic microbes substitute hydrogen (H) for chlorine on chlorinated contaminant molecules thus dechlorinating the compound. While this is a natural process, it usually proceeds in the groundwater environment at slow rates that are not sustainable. ***HRC increases the rate of dechlorination an order of magnitude or more, rapidly taking the contaminant through a step-wise dechlorination process that ultimately results in non-toxic compounds such as ethene and ethane.***

HRC is a proprietary, environmentally safe polylactate ester specially formulated for slow release of lactic acid upon contact with water in the subsurface environment. Once in place, the HRC slowly and continuously releases lactic acid. Indigenous anaerobic microbes then metabolize the lactic acid generated by HRC and produce hydrogen. The resulting continuous, low concentration of hydrogen is then used by reductive dechlorinating microbes to rapidly dechlorinate the contaminant for over a year's time.

Figure 4: HYDROGEN RELEASE COMPOUND, HRC
Role in Enhanced Reductive Dechlorination



HRC may favor reductive dechlorination over competing methanogenic activity

Within the subsurface anaerobic microbial consortium, there exists microbes that use hydrogen primarily for the production of methane (methanogens), and those that use hydrogen primarily for dechlorination (reductive dechlorinators). Results from university studies suggest that there is competition for hydrogen between the reductive dechlorinators and methanogens (Fennell, et al., 1997; Yang and McCarty, 1999). High hydrogen concentrations may favor methanogenic activity, whereas reductive dechlorinators are best supported in conditions of moderate hydrogen concentrations (2-10 nM). Thus, since HRC's long-lasting time-release feature facilitates moderate hydrogen concentrations, it may be an ideal approach for optimizing reductive dechlorination over competing methanogenic activity.

Plume Treatment

HRC is injected directly into the plume area through multiple push-points or boreholes. Once in place the HRC stimulates the rapid degradation of target contaminants in the subsurface.

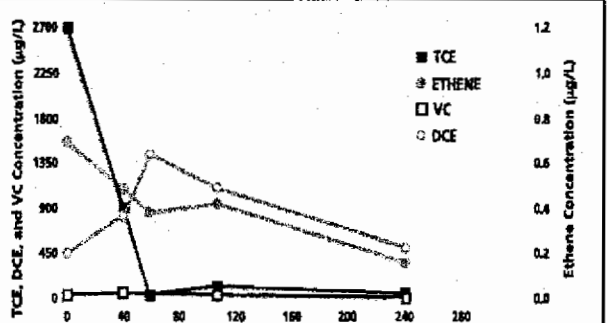
Benefits:

- Low cost treatment
- Simple to apply with minimal disruption
- No safety concerns as with oxidizing chemicals
- No operations and maintenance

Case History:

HRC was selected as the technology to treat a TCE plume within a sandy aquifer at a military base in Florida. A total of a 6000 pounds of HRC was injected into the core of a plume within 25 push-points across a 30' interval. An estimated 4000 sq. ft. area was treated. Results collected over a 240 day period indicated excellent performance with the HRC completely dechlorinating the TCE through to ethene. This project was accomplished for $36,000 in HRC cost and an estimated $3,000 in push-point subcontractor costs.

Figure 1: CHANGE IN TCE, DCE, VC & ETHENE
Upon HRC Application in Florida



Plume Cut-Off

HRC is injected directly across the migrating plume in push-points or boreholes. Once in place, the HRC stimulates the rapid degradation of the migrating target compounds, effectively cutting-off the plume in the form of a permeable reactive barrier.

Benefits:

- Effectively contains plume
- No wells or trenching required
- Low cost treatment
- No safety concerns as with oxidizing chemicals
- No operations and maintenance

Case History:

At a former manufacturing facility in Ohio, DCE and vinyl chloride (VC) groundwater contaminants in a bedrock aquifer were migrating off-site generating considerable potential liability. A line of open-rock HRC filled borings were installed to cut-off the plume. Results of the application were excellent with >99% reduction in DCE and >99% reduction in VC. This application was performed at a fraction of the cost of competing technologies such as the construction of iron walls or inefficient pump and treat systems.

Figure 2: PLUME CUT-OFF

Anaerobic Test		DCE			VC		
Well	Location	Baseline Jul-99	180 Days Jan-00	Percent Reduction	Baseline Jul-99	180 Days Jan-00	Percent Reduction
H-1	20' upgradient	5,700	2,000	65%	450	200	56%
H-2	5' downgradiant	2,600	1,100	58%	1,200	240	72%
H-3	25' downgradiant	590	3	99.6%	210	1	99.5%

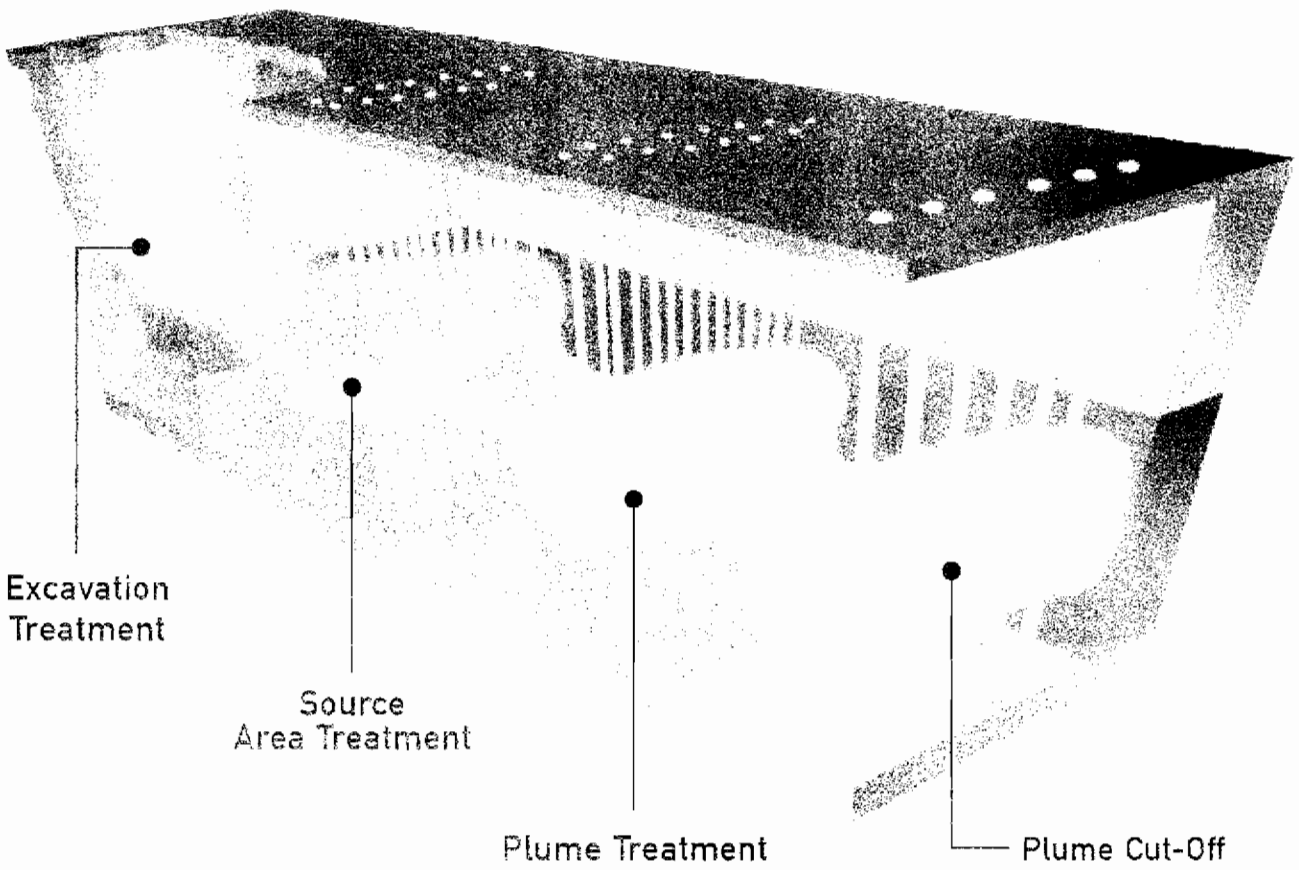
Simple and Inexpensive to Apply

HRC is manufactured as a viscous liquid that is pumped into the contaminated aquifer via direct-push equipment or augered boreholes. HRC can also be placed directly into open excavations prior to backfilling.

Treats a Range of Contaminants

HRC is widely applied for the cost-effective treatment of chlorinated solvent contaminants such as PCE, TCE, TCA, carbon tetrachloride and their derivatives. HRC has also been shown to effectively treat chlorinated pesticides, PCP, perchlorate, nitrate and chromium.

HRC Applications are Flexible and Can Be Designed to Meet a Variety of Objectives:



Excavation Treatment

HRC is placed into the bottom of open excavations prior to backfilling. Once in place the HRC stimulates the rapid degradation of the target compounds directly at the source of the contamination.

Benefits:

- Low cost source area treatment
- Easily applied along with planned excavations
- No operations or maintenance
- No safety concerns as with oxidizing chemicals

Case History:

At a commercial dry cleaning facility in Washington, a pipe leak caused PCE to contaminate groundwater at very high concentrations. HRC was injected in a plume treatment. The source area soils were excavated to groundwater surface, and HRC was placed within the excavation prior to back-filling with clean soil. After 328 days of HRC release activity, the PCE concentration had dropped by 99% (from a high of 67,400 ppb to 259 ppb).

Source Area Treatment

HRC is injected directly into the source area through multiple push-points or boreholes. Once in place the HRC stimulates the desorption and degradation of the contaminants within the source zone.

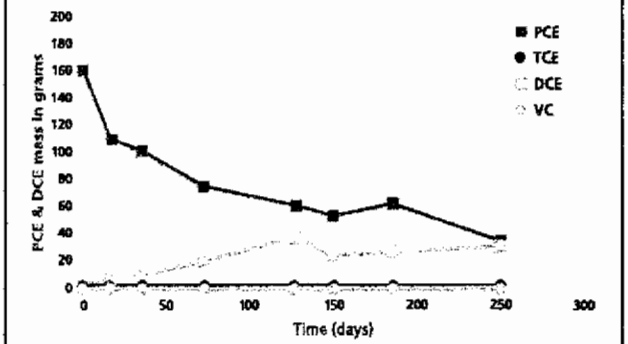
Benefits:

- Low cost source area treatment
- Desorbs and degrades residual DNAPL
- No safety concerns as with oxidizing chemicals
- No operations and maintenance

Case History:

At a dry cleaning facility in Wisconsin, HRC was applied to treat groundwater contamination in the source area of a PCE spill. Dissolved PCE concentrations were in excess of 22,000 ppb indicating the presence of nearby residual DNAPL. Within 250 days of a single HRC application, dissolved PCE mass had decreased 80% with concentrations averaging less than 3,000 ppm across the treated source area.

Figure 3: CHANGE IN PCE, TCE, DCE & VC MASS
Upon HRC Application in Wisconsin



HRC®: Cost-Effective Remediation

HRC offers a cost-effective, *in situ* method of treating chlorinated compounds. The material is applied very inexpensively using push-point or borehole delivery methods, and once in place a single HRC application continues to treat the contaminant plume for a year's time. It is this low cost of application and the elimination of operation and maintenance costs that gives HRC technology its dramatic cost advantage over other treatment options.

Plume Treatment

Figure 5 displays a cost comparison of HRC to other viable options for treating four typical plume scenarios assuming a TCE contaminant concentration of 10 ppm.

Figure 5: PLUME-WIDE REMEDIATION COST COMPARISON TECHNOLOGY COST COMPARISON ($)*

	Smaller Site (50' x 75')		Larger Site (200' x 200')	
	Shallow Aquifer (20' bgs)	Deeper Aquifer (50' bgs)	Shallow Aquifer (20' bgs)	Deeper Aquifer (50' bgs)
HRC Treatment	130,000	134,000	316,000	324,000
Pump and Treat	595,000	633,000	778,000	876,000
Air Sparging w/SVE	334,000	358,000	639,000	760,000
Chemical Oxidation	320,000	343,00	1,495,000	1,636,000

** Comparison costs were generated by an independent environmental consulting firm and include costs through project completion, e.g. sampling, monitoring, reporting, etc. All costs are reported in today's dollars. A net present value analysis would make HRC treatment appear considerably more favorable.*

Plume Cut-Off

Figure 6 displays a cost comparison of HRC to other viable options for cutting-off a migrating plume under four typical plume scenarios assuming a TCE contaminant concentration of 10 ppm.

Figure 6: PLUME CUT-OFF BARRIER TECHNOLOGY COST COMPARISON ($)*

	Smaller Plume (50' wide)		Larger Plume (200' wide)	
	Shallow Aquifer (20' bgs)	Deeper Aquifer (50' bgs)	Shallow Aquifer (20' bgs)	Deeper Aquifer (50' bgs)
HRC Treatment	145,000	145,500	175,000	176,000
Iron Wall Permeable Barrier	336,914	394,514	632,586	776,586
Pump and Treat	578,945	615,265	685,893	757,443
Air Sparging w/SVE	350,825	356,525	641,767	675,017

** Comparison costs were generated by an independent environmental consulting firm and include all project costs for operating a plume cut-off for a five year period. All costs are reported in today's dollars. A net present value analysis would make HRC treatment appear considerably more favorable.*

HRC is a sensible, cost-effective solution for treating chlorinated contaminants in groundwater and for restoring property values.

REGENESIS

1011 Calle Sombra • San Clemente • California 92673
Tel: 949. 366. 8000. • Fax: 949. 366. 8090. • e-mail: orc@regenesis.com • www.regenesis.com

United States Environmental Protection Agency | Solid Waste and Emergency Response (5102G) | EPA 542-N-00-006 September 2000 Issue No. 37

EPA

Ground Water Currents

Developments in Innovative Ground Water Treatment

CONTENTS

About this Issue

This issue highlights the use of peroxide, ozone, and permanganate in remediating ground water through chemical oxidation/reduction. In addition, it includes a description of results obtained in field uses of phytoremediation and biologically enhanced reductive dechlorination.

In Situ Chemical Oxidation for Remediation of Contaminated Soil and Ground Water

by Robert L. Siegrist, Colorado School of Mines; Michael A. Urynowicz, ENVIROX, LLC; and Olivia R. West, Oak Ridge National Laboratory

Introduction

Chemical oxidation/reduction has proven to be an effective *in situ* remediation technology for ground water contaminated by toxic organic chemicals. The oxidants most commonly employed to date include peroxide, ozone, and permanganate. These oxidants have been able to cause the rapid and complete chemical destruction of many toxic organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bioremediation. In general the oxidants have been capable of achieving high treatment efficiencies (*e.g.*, > 90 percent) for unsaturated aliphatic (*e.g.*, trichloroethylene [TCE]) and aromatic compounds (*e.g.*, benzene), with very fast reaction rates (90 percent destruction in minutes). Field applications have clearly affirmed that matching the oxidant and *in situ* delivery system to the contaminants of concern (COCs) and the site conditions is the key to successful implementation and achieving performance goals.

Oxidants and Reaction Chemistry

Peroxide (See Table 1) Oxidation using liquid hydrogen peroxide (H_2O_2) in the presence of native or supplemental ferrous iron (Fe^{+2}) produces Fenton's Reagent which yields free hydroxyl radicals ($OH^{\cdot}$). These strong, nonspecific oxidants can rapidly degrade a variety of organic compounds. Fenton's Reagent oxidation is most effective under very acidic pH (*e.g.*, pH 2 to 4) and becomes ineffective under moderate to strongly alkaline conditions. The reactions are extremely rapid and follow second-order kinetics. The simplified stoichiometric reaction for peroxide degradation of TCE is given by equation (a).

$$3H_2O_2 + C_2HCl_3 \rightarrow 2CO_2 + 2H_2O + 3HCl \quad (a)$$

Ozone (See Table 1) Ozone gas can oxidize contaminants directly or through the formation of hydroxyl radicals. Like peroxide, ozone reactions are most effective in systems with acidic pH. The oxidation reaction proceeds with extremely fast, pseudo

[continued on page 2]

[continued from page 4]

and environmentally sound clean up solution for contaminated ground water.

For further information contact Dr. Lee Newman at 206-616-2388 or 206-890-1090 or E-mail newmanla@u.washington.edu, or Dr. Milton Gordon at 206-543-1769 or E-mail miltong@u.washington.edu.

Enhanced Biological Reductive Dechlorination at a Dry Cleaning Facility

by Judie A. Kean, Florida Department of Environmental Protection; Michael N. Lodato, IT Corporation; and Duane Graves, Ph.D., IT Corporation

The dry cleaning industry uses tetrachloroethylene (PCE) as a degreaser and waterless cleanser for clothes. The use of PCE has resulted in the release of this chlorinated solvent at numerous dry cleaning facilities. In the past, many dry cleaning businesses were independently owned with little regulatory oversight regarding the disposal and storage of solvents. As a result, PCE contamination of both soil and ground water at dry cleaner sites is very common.

Under the auspices of the Florida Department of Environmental Protection, and in accordance with the State's Dry Cleaning Solvent Cleanup Program, a commercial dry cleaning facility's soil and ground water was extensively characterized with state-of-the art direct-push diagnostic protocols and statistical data confidence software. The total scope of work was designed to include the evaluation of parameters which give both qualitative and quantitative indications of the occurrence of reductive dechlorination of chlorinated solvents. The combined evidence generated from several different aspects of this evaluation suggested that natural attenuation by the process of reductive dechlorination was occurring, and was significantly affecting the fate of chlorinated compounds in the aquifer.

Measurable levels of *cis*-1,2-DCE (dichloroethylene) and vinyl chloride supported the conclusion that reductive dechlorination of PCE and TCE (trichloroethylene) affected the chemical composition of a dissolved contaminant ground-water plume. Upon evaluation of all assessment data, it was determined that an area of approximately 14,600 square feet of contaminated ground water was situated within the 1 mg/L isopleth for PCE; and in some monitoring wells contaminant concentrations approached 9 mg/L.

HRC Application and Monitoring Program

Approximately 6,800 pounds of Hydrogen Release Compound (HRC) were injected into the area described via 144 direct-push points spaced 10 feet apart on centers within an 80-ft by 180-ft grid. HRC is a proprietary, environmentally safe, food quality, polylactate ester made by Regenesis Bioremediation Products, Inc. It is specially formulated for slow release of lactic acid upon hydration. HRC is applied to the subsurface via push-point injection or within dedicated wells. HRC is then left in place where it passively works to stimulate rapid contaminant degradation. At the Florida site, each point received 2.45 gallons of HRC between a depth of 5 to 30 feet below the surface in the upper surficial aquifer.

The effects of HRC on ground-water geochemistry and chlorinated solvent concentrations were determined by periodically sampling and analyzing ground water from seven monitoring wells. Analysis included chlorinated solvents, dissolved oxygen, oxidation-reduction potential, pH, conductivity, temperature, ferrous iron, nitrate and nitrite, sulfate, methane, ethane, ethene, manganese, and phosphorus.

Ground-water samples were collected for six months following the HRC application to monitor progress of the treatment.

Results

The application of HRC resulted in an observable change in the concentration of chlorinated solvents. An area approximately 240 by 180 feet was affected by the HRC application. The mass of PCE and its dechlorination products before HRC application and at various time points after the application is shown in Table 3 on page 6.

The PCE mass increased from the initial mass to the mass estimated after 43 days. This change was presumably due to physical desorption related to the injection activity. Overall the PCE mass was reduced by 96% after 152 days of treatment. The dramatic reduction in PCE mass and the less dramatic reduction of the mass of the lesser chlorinated ethenes suggests that the PCE was being dechlorinated to TCE, DCE, and vinyl chloride. HRC-stimulated, biologically mediated, reductive dechlorination of PCE was confirmed by changes in ground-water geochemistry that are typically catalyzed by biological activity.

[continued on page 6]

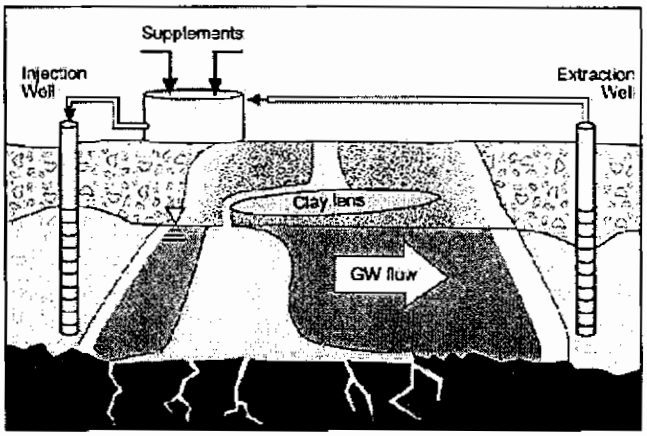
United States
Environmental Protection Agency

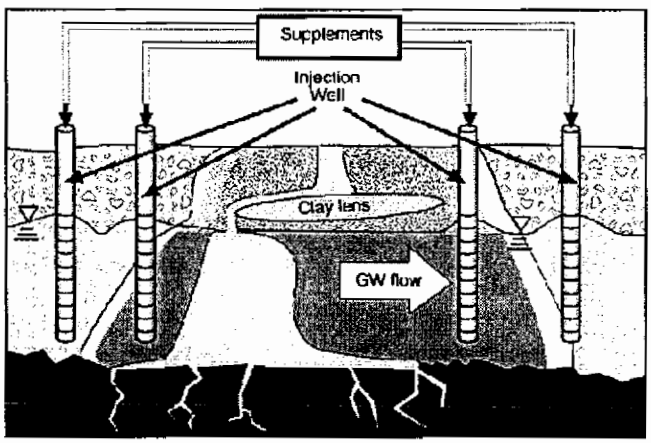
Solid Waste and
Emergency Response
(5102G)

EPA 542-R-00-008
July 2000
www.epa.gov
clu-in.org

EPA

Engineered Approaches to *In Situ* Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications





EPA 542-R-00-008
July 2000

ENGINEERED APPROACHES TO *IN SITU* BIOREMEDIATION OF CHLORINATED SOLVENTS: FUNDAMENTALS AND FIELD APPLICATIONS

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

NOTICE AND DISCLAIMER

This document was prepared by the U.S. Environmental Protection Agency's Technology Innovation Office under EPA Contract Number 68-W-99-003. Information in this report is derived from a variety of references (including personal communications with experts in the field), some of which have been peer-reviewed. This report has undergone EPA and external review by experts in the field. Key terms used in this report are defined in a glossary, and shown in bold print. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. For more information about this project, please contact: Linda Fiedler, U.S. Environmental Protection Agency, Technology Innovation Office, Ariel Rios Building, 1200 Pennsylvania Avenue, N.W. (MS 5102G), Washington, D.C., 20460; (703) 603-7194; e-mail: *fiedler.linda@epa.gov*.

This document may be obtained from EPA's web site at *www.epa.gov/tio/*, or at *clu-in.org*. A limited number of hard copies of this document are available free of charge by mail from EPA's National Service Center for Environmental Publications, at the following address (please allow 4 to 6 weeks for delivery):

U.S. EPA/National Service Center for Environmental Publications
P.O. Box 42419
Cincinnati, OH 45242
Phone: (513) 489-8190 or (800) 490-9198
Fax: (513) 489-8695

ACKNOWLEDGMENTS

Special acknowledgment is given to the following individuals for their thoughtful suggestions and support in preparing this report: Lewis Semprini, Oregon State University; David Steckel, Edwards Air Force Base; Perry McCarty, Stanford University; Kurt Gerdes, the U.S. Department of Energy; David W. Anderson and Susan Litherland, Roy F. Weston, Inc.; Daniel L. Jacobs, ARCADIS Geraghty & Miller; Willard Murray, Harding Lawson Associates; Mick Mikula, Dover Air Force Base; and David Ellis, E.I. du Pont de Nemours and Company.

FOREWORD

Halogenated volatile organic compounds, including chlorinated solvents, are the most frequently-occurring type of soil and groundwater contaminant at Superfund and other hazardous waste sites in the United States. The U.S. Environmental Protection Agency (EPA) estimates that, over the next several decades, site owners will spend billions of dollars to clean up these sites. New technologies that are less costly and more effective are needed to accomplish hazardous waste site remediation. As these new and innovative technologies are being developed and used, site managers require information on how they work, their performance to date, and how to evaluate their application at a particular site.

This report provides an overview of the fundamentals and field applications of *in situ* bioremediation to remediate chlorinated solvents in contaminated soil and groundwater. *In situ* treatment is increasingly being selected to remediate sites because it is usually less expensive, and does not require waste extraction or excavation. In addition, *in situ* bioremediation is more publicly acceptable than above-ground technologies because it relies on natural processes to treat contaminants.

This document presents information at a level of detail intended to familiarize federal and state project managers, permit writers, technology users, and contractors with *in situ* bioremediation. The report describes how chlorinated solvents are degraded, how to enhance the process by the addition of various materials and chemicals, design configurations, and the typical steps taken to evaluate technology feasibility at a specific site. It also includes a list of technology vendors and nine case studies of field applications.

It is important to note that this report cannot be used as the sole basis for determining this technology's applicability to a specific site. That decision is based on many factors and must be made on a case-by-case basis. Technology expertise and sometimes treatability studies also are required to make a final remedy decision.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF EXHIBITS

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/R-98/128
September 1998

EPA

Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water

TECHNICAL PROTOCOL FOR EVALUATING NATURAL ATTENUATION OF CHLORINATED SOLVENTS IN GROUND WATER

by

Todd H. Wiedemeier
Parsons Engineering Science, Inc.
Pasadena, California

Matthew A. Swanson, David E. Moutoux, and E. Kinzie Gordon
Parsons Engineering Science, Inc.
Denver, Colorado

John T. Wilson, Barbara H. Wilson, and Donald H. Kampbell
United States Environmental Protection Agency
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
Ada, Oklahoma

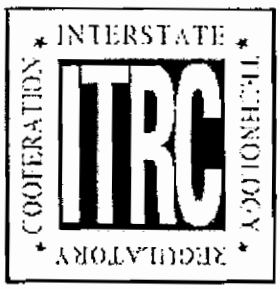
Patrick E. Haas, Ross N. Miller and Jerry E. Hansen
Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base, Texas

Francis H. Chapelle
United States Geological Survey
Columbia, South Carolina

IAG #RW57936164

Project Officer
John T. Wilson
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
Ada, Oklahoma

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268



TECHNICAL REQUIREMENTS

NATURAL ATTENUATION OF CHLORINATED SOLVENTS IN GROUNDWATER: PRINCIPLES AND PRACTICES

-FINAL-

May 1999

Prepared by:

The Interstate Technology and Regulatory Cooperation Work Group, In Situ Bioremediation Work Team

The Industrial Members of the Bioremediation of Chlorinated Solvents Consortium of the Remediation Technologies Development Forum (RTDF)

GeoSyntec Consultants
Dow Chemical Company
DuPont Company
General Electric Company
Imperial Chemical Industries
Mosanto Company
Novartis
Zeneca Inc.

TABLE OF CONTENTS

Page

LIST OF TABLES

(All are found in Appendix D)

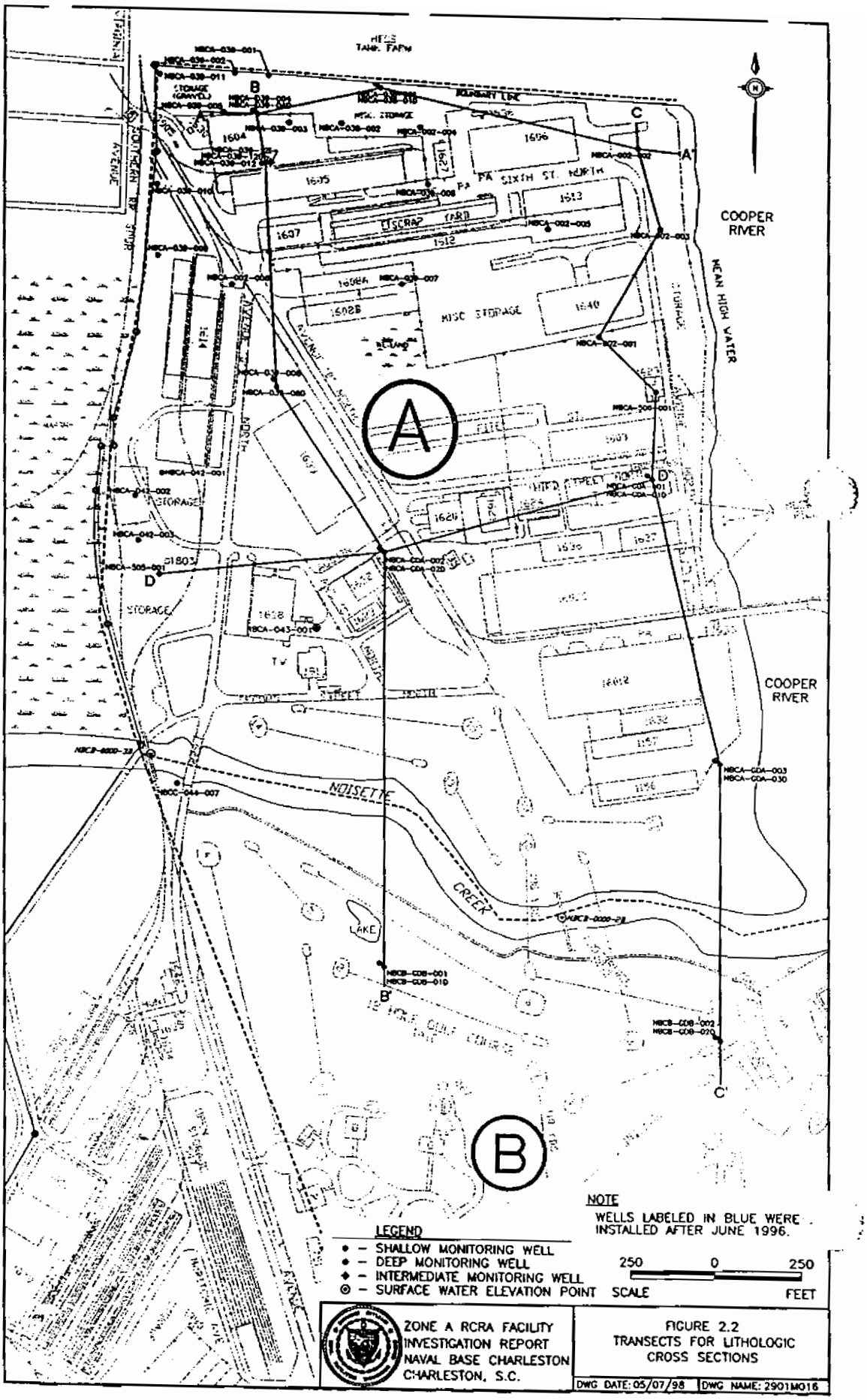
LIST OF FIGURES

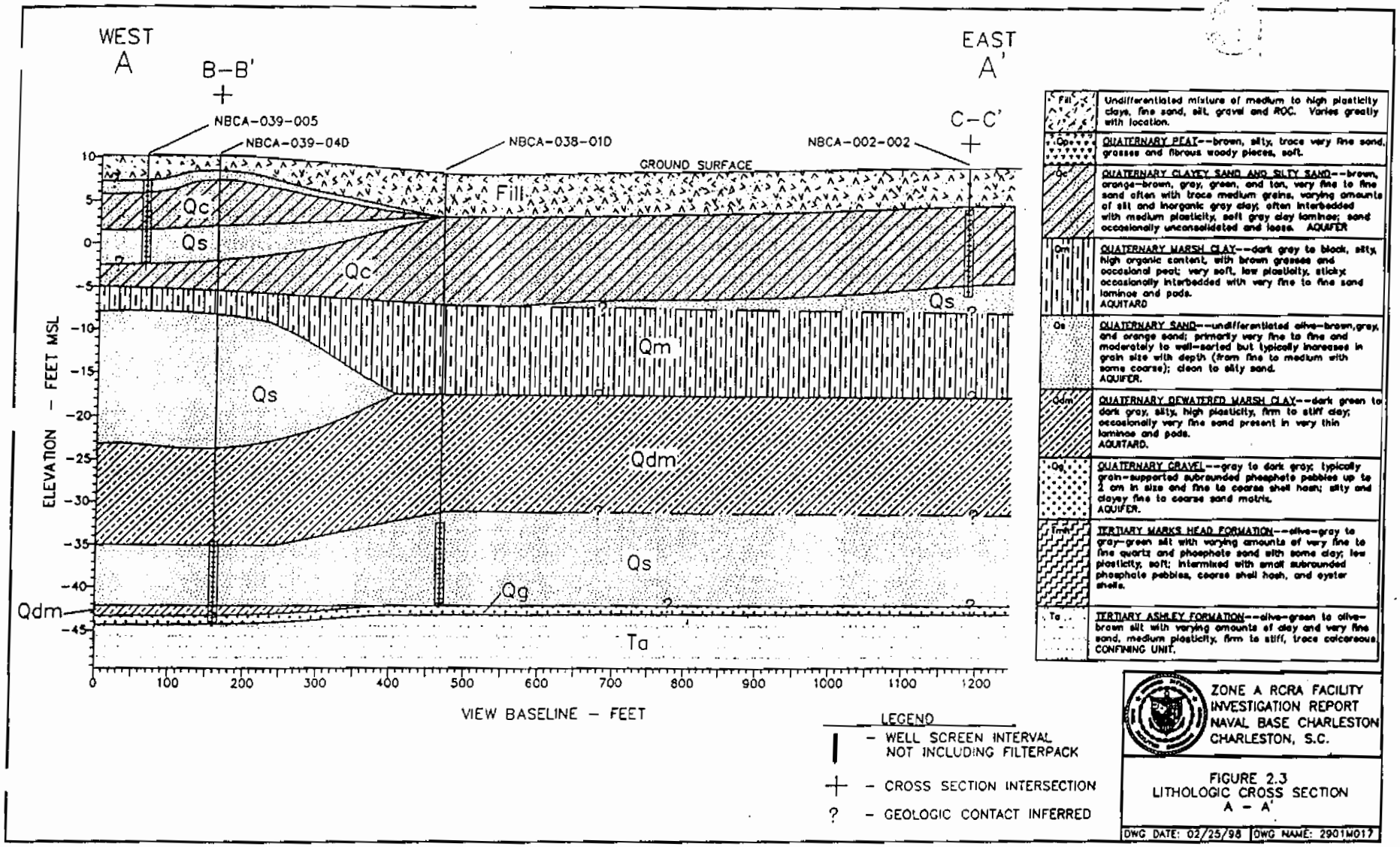
(All are found in Appendix D)

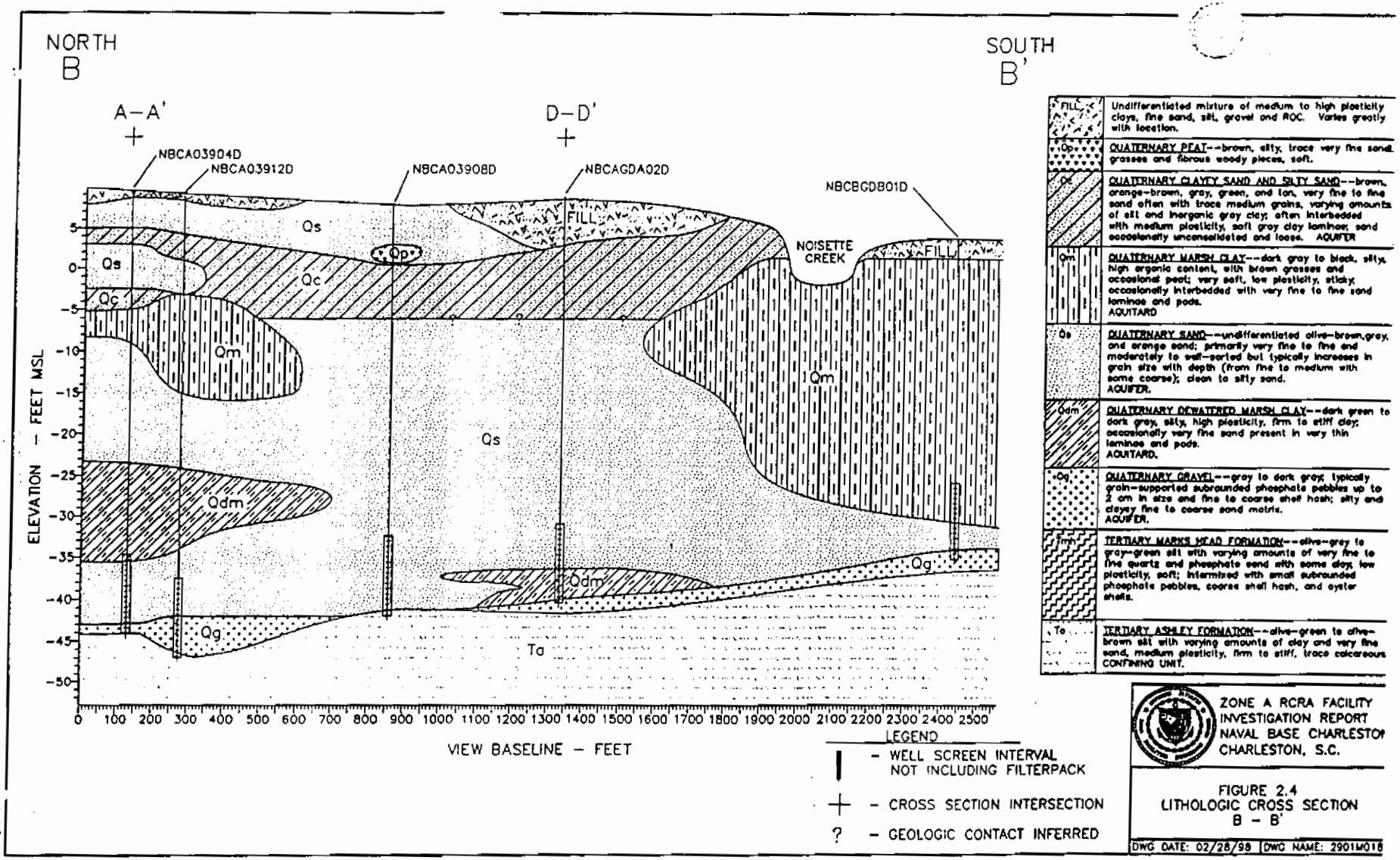
LIST OF APPENDICES

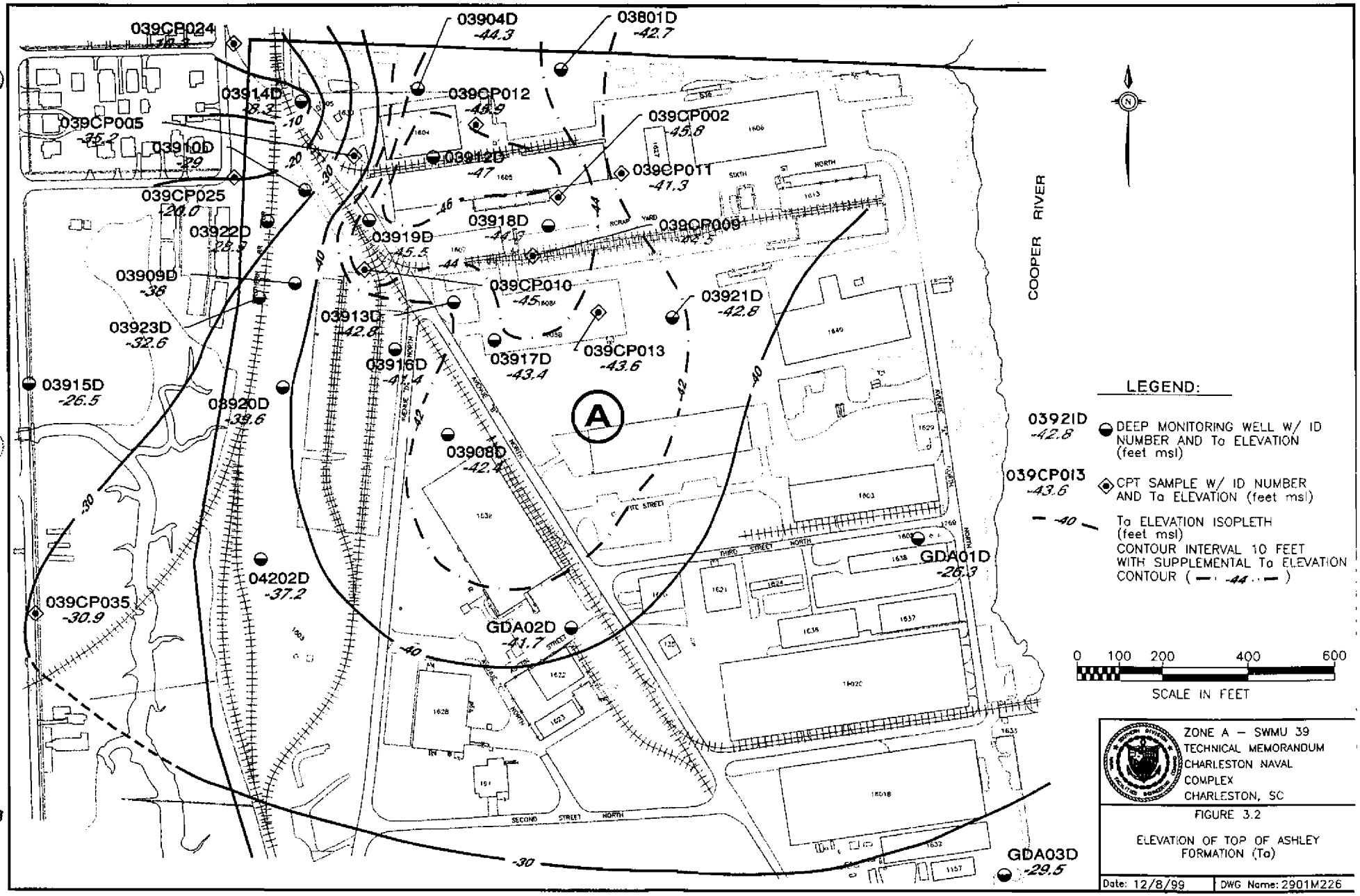
APPENDIX C

Geologic Cross Sections and Structural Contours


COOPER RIVER
MEAN HIGH WATER
COOPER RIVER
NOISETTE CREEK
LAKE
A
B
C
D
A'
B'
C'
D'
NOTE
WELLS LABELED IN BLUE WERE INSTALLED AFTER JUNE 1996.
LEGEND
• – SHALLOW MONITORING WELL
• – DEEP MONITORING WELL
◆ – INTERMEDIATE MONITORING WELL
◎ – SURFACE WATER ELEVATION POINT
250 0 250
SCALE FEET
ZONE A RCRA FACILITY INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.
FIGURE 2.2
TRANSECTS FOR LITHOLOGIC CROSS SECTIONS
DWG DATE: 05/07/98
DWG NAME: 2901M016


WEST
A
B–B'
EAST
A'
C–C'
NBCA-039-005
NBCA-039-04D
NBCA-038-01D
NBCA-002-002
GROUND SURFACE
Fill
Qc
Qs
Qm
Qdm
Qg
Ta
ELEVATION – FEET MSL
VIEW BASELINE – FEET
LEGEND
– WELL SCREEN INTERVAL NOT INCLUDING FILTERPACK
– CROSS SECTION INTERSECTION
? – GEOLOGIC CONTACT INFERRED
Undifferentiated mixture of medium to high plasticity clays, fine sand, silt, gravel and ROC. Varies greatly with location.
QUATERNARY PEAT--brown, silty, trace very fine sand, grasses and fibrous woody pieces, soft.
QUATERNARY CLAYEY SAND AND SILTY SAND--brown, orange-brown, gray, green, and tan, very fine to fine sand often with trace medium grains, varying amounts of silt and inorganic gray clay; often interbedded with medium plasticity, soft gray clay laminae; sand occasionally unconsolidated and loose. AQUIFER
QUATERNARY MARSH CLAY--dark grey to black, silty, high organic content, with brown grasses and occasional peat; very soft, low plasticity, sticky; occasionally interbedded with very fine to fine sand laminae and pods. AQUITARD
QUATERNARY SAND--undifferentiated olive-brown, gray, and orange sand; primarily very fine to fine and moderately to well-sorted but typically increases in grain size with depth (from fine to medium with some coarse); clean to silty sand. AQUIFER.
QUATERNARY DEWATERED MARSH CLAY--dark green to dark gray, silty, high plasticity, firm to stiff clay; occasionally very fine sand present in very thin laminae and pods. AQUITARD.
QUATERNARY GRAVEL--gray to dark gray; typically grain-supported subrounded phosphate pebbles up to 2 cm in size and fine to coarse shell hash; silty and clayey fine to coarse sand matrix. AQUIFER.
TERTIARY MARKS HEAD FORMATION--olive-gray to gray-green silt with varying amounts of very fine to fine quartz and phosphate sand with some clay; low plasticity, soft; intermixed with small subrounded phosphate pebbles, coarse shell hash, and oyster shells.
TERTIARY ASHLEY FORMATION--olive-green to olive-brown silt with varying amounts of clay and very fine sand, medium plasticity, firm to stiff, trace calcareous. CONFINING UNIT.
ZONE A RCRA FACILITY INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.
FIGURE 2.3
LITHOLOGIC CROSS SECTION
A – A'
DWG DATE: 02/25/98
DWG NAME: 2901M017


NORTH
B
SOUTH
B'
A–A'
D–D'
NBCA03904D
NBCA03912D
NBCA03908D
NBCAGDA02D
NBCBGDB01D
NOISETTE CREEK
FILL
Qs
Qp
Qc
Qm
Qdm
Qg
Ta
ELEVATION – FEET MSL
5
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
VIEW BASELINE – FEET
FILL Undifferentiated mixture of medium to high plasticity clays, fine sand, silt, gravel and ROC. Varies greatly with location.
Qp QUATERNARY PEAT--brown, silty, trace very fine sand, grasses and fibrous woody pieces, soft.
Qc QUATERNARY CLAYEY SAND AND SILTY SAND--brown, orange-brown, gray, green, and tan, very fine to fine sand often with trace medium grains, varying amounts of silt and inorganic gray clay; often interbedded with medium plasticity, soft gray clay laminae; sand occasionally unconsolidated and loose. AQUIFER
Qm QUATERNARY MARSH CLAY--dark gray to black, silty, high organic content, with brown grasses and occasional peat; very soft, low plasticity, sticky; occasionally interbedded with very fine to fine sand laminae and pods. AQUITARD
Qs QUATERNARY SAND--undifferentiated olive-brown, gray, and orange sand; primarily very fine to fine and moderately to well-sorted but typically increases in grain size with depth (from fine to medium with some coarse); clean to silty sand. AQUIFER.
Qdm QUATERNARY DEWATERED MARSH CLAY--dark green to dark gray, silty, high plasticity, firm to stiff clay; occasionally very fine sand present in very thin laminae and pods. AQUITARD.
Qg QUATERNARY GRAVEL--gray to dark gray; typically grain-supported subrounded phosphate pebbles up to 2 cm in size and fine to coarse shell hash; silty and clayey fine to coarse sand matrix. AQUIFER.
Tm TERTIARY MARKS HEAD FORMATION--olive-gray to gray-green silt with varying amounts of very fine to fine quartz and phosphate sand with some clay, low plasticity, soft; intermixed with small subrounded phosphate pebbles, coarse shell hash, and oyster shells.
To TERTIARY ASHLEY FORMATION--olive-green to olive-brown silt with varying amounts of clay and very fine sand, medium plasticity, firm to stiff, trace calcareous CONFINING UNIT.
LEGEND
– WELL SCREEN INTERVAL NOT INCLUDING FILTERPACK
– CROSS SECTION INTERSECTION
? – GEOLOGIC CONTACT INFERRED
ZONE A RCRA FACILITY INVESTIGATION REPORT
NAVAL BASE CHARLESTON
CHARLESTON, S.C.
FIGURE 2.4
LITHOLOGIC CROSS SECTION
B – B'
DWG DATE: 02/28/98
DWG NAME: 2901M018


039CP024
-38.2
03904D
-44.3
03801D
-42.7
03914D
-38.2
039CP012
-45.9
039CP005
-35.2
039CP002
-45.8
03910D
-39
03912D
-47
039CP011
-41.3
039CP025
-20.0
03918D
-44
039CP009
-29.5
03922D
-28.5
03919D
-45.5
03909D
-36
039CP010
-45
03921D
-42.8
03923D
-32.6
03913D
-42.8
03917D
-43.4
039CP013
-43.6
03916D
-41.4
03915D
-26.5
03920D
-39.6
03908D
-42.4
GDA01D
-26.3
04202D
-37.2
039CP035
-30.9
GDA02D
-41.7
GDA03D
-29.5
A
COOPER RIVER
SIXTH ST NORTH
THIRD STREET NORTH
SECOND STREET NORTH
LEGEND:
03921D
-42.8
DEEP MONITORING WELL W/ ID NUMBER AND To ELEVATION (feet msl)
039CP013
-43.6
CPT SAMPLE W/ ID NUMBER AND To ELEVATION (feet msl)
To ELEVATION ISOPLETH (feet msl) CONTOUR INTERVAL 10 FEET WITH SUPPLEMENTAL To ELEVATION CONTOUR
0 100 200 400 600
SCALE IN FEET
ZONE A – SWMU 39
TECHNICAL MEMORANDUM
CHARLESTON NAVAL COMPLEX
CHARLESTON, SC
FIGURE 3.2
ELEVATION OF TOP OF ASHLEY FORMATION (Ta)
Date: 12/8/99
DWG Name: 2901M226

APPENDIX D

Response to SCDHEC Comments

December 19, 2000 158814.ZA.PR.01

Mr. Mihir Mehta
South Carolina Department of Health and Environmental Control
Bureau of Land and Waste Management
8901 Farrow Road
Columbia, SC 29201

RE: Response to SCDHEC Comments on Corrective Measures Study Work Plan, October, 2000, Charleston Naval Complex, Zone A, SWMU 39.

Dear Mr. Mehta:

With this letter CH2M-Jones is presenting the enclosed responses to SDCHEC comments, regarding the RCRA Corrective Measures Study Work Plan for hydrogen release compound (HRC) Pilot Test.

Our responses address comments made by Mr. Monsour Malik and Ms. Elizabeth Frady, received by CH2M-Jones electronically on December 7, 2000. Our responses are organized in the same format as they were presented in the SCDHEC comments, with our response appearing directly beneath each respective comment.

Our proposed changes to the CMS Work Plan are presented with the responses. If our proposed changes sufficiently address SCDHEC's concerns, please notify me as soon as possible, so that revisions to the CMS Work Plan can begin without delay.
Please phone me at 352-335-5877, ext. 477 with any questions regarding this submittal, or via e-mail at welliott@ch2m.com.

Sincerely,

CH2M-Jones

William G. Elliott, P.G.
Project Hydrogeologist

Enclosure
cc: Dean Williamson, Tom Beisel

CH2M-Jones Response to SCDHEC Comments
Draft SWMU 39 Corrective Measures Study
December 18, 2000

FROM: Elizabeth Frady
Corrective Action Engineering Section
Bureau of Land and Waste Management
South Carolina Department of
Health and Environmental Control

DATE: December 5, 2000

RE: Charleston Naval Complex Enhanced In Situ Biodegradation Pilot Test for SWMU 39, Zone A, Dated October 2000

The above referenced document has been reviewed with regard to the requirements of the SRS Hazardous Waste Permit and the South Carolina Hazardous Waste Management Regulations. As a result of this review, the following comments have been generated:

Specific Comments:

1. According to the last sentence of Section 2.1, Current Nature and Extent of Contamination, "At well A039GW023D...compounds are now being detected...indicating either a diffuse local source or arrival of the leading edge of the groundwater plume..." Please clarify how this uncertainty will affect the understanding of results obtained from HRC injection in this area.

Response: In the CMS Work Plan, Geoprobe sampling is proposed to more accurately determine the western groundwater plume component near the base boundary. It is believed that the VOCs observed in groundwater at well cluster A039GW023 are from an upgradient source, as no VOC source is known to exist near these wells. Two new wells (A039GW024I and D) are also proposed upgradient of well cluster A039GW023 – see Figure 5-5 of the Work Plan. Sampling results and groundwater level measurements from these new wells will assist in determining plume geometry and local groundwater flow conditions, as well as possible use for HRC effectiveness. HRC will still be injected at this grid location as a downgradient migration barrier experiment, even if it is determined that the plume has not yet reached any of these wells.

The Work Plan text in lines 16-17 of Section 2.1 will be revised to read: " ...indicating either a diffuse local source or arrival of the leading edge of the dissolved VOC groundwater plume originating from the interior of the SWMU 39 area. Both of these aquifer conditions can be effectively treated by injection of HRC, and the exact conditions under which the VOCs were introduced is not critical to the success of the pilot test."

2. The term "source" is used in several contexts throughout the document. "Source" is typically understood by the Department to be an original release mechanism (such as an underground tank, buried waste or highly contaminated soil that continues to leach to groundwater). The statement beginning on Line 8, Section 3.1 reads, "Because no discrete VOC sources were identified in soils during the RFI, groundwater contaminant source control is expected to be the primary remedial action required to reduce VOC concentrations..." This implies that the groundwater itself is a source, which is inaccurate. Contamination in groundwater may be uncontrolled, however no additional contamination is being introduced into the system. Clarity with regard to the concept of "source" will help a great deal with delineation of the site condition and will facilitate document review.

Response: In the context of the CMS work Plan, the term "source" was used to describe any "source area" where a release of VOCs to groundwater could have occurred. The term "source" was also meant to imply the relationship that exists between the presence of "parent" VOCs such as PCE and TCE, which are the sources of degradation VOCs such as DCE and Vinyl Chloride, also known as "daughter products".

The text of line 9 of Section 3.1 of the Work Plan will be changed to read: " Because no discrete VOC sources were identified in soils during the RFI, ~~groundwater contaminant source control~~ *dissolved phase VOC groundwater plume treatment* is expected to be the primary remedial action required.... "

3. The addition of the most recent plume interpretation included in all of the Figures in Section 5 would help to illustrate the rationale for placing the injection locations. Please amend the Figures to show this information.

Response: A complete round of recent sampling data for all wells in the study area is not available, precluding the development of a meaningful iso-concentration contour map for current VOC distribution in groundwater. We will construct a limited plume boundary map using historical Ensafe data, and data from the sampling CH2M Hill performed in SWMU 39 as part of the basewide groundwater monitoring program in July

2000. These two data sets will be combined to generate a complete but approximate VOC distribution map; however, some sampling dates will be different.

Figures 5-1 and 5-5 of the Work Plan, which show the entire plume area, will be revised to include an isocontour line showing the approximate distribution of indicator VOCs exceeding MCLs in groundwater.

4. The symbols for wells A039GW023 and A039GW023D are different from the symbol listed in the legend and those depicting other wells in Figures 5-1, 5-4 and 5-5. Please either include this symbol in the legend with an appropriate explanation or change the symbol to be consistent with the other wells.

Response: This discrepancy is a GIS artifact; these wells are existing monitor wells. The figure will be corrected to use the same symbols for all wells.

5. Section 5.2 notes that CH2M Hill will coordinate with the appropriate DHEC personnel to arrange for UIC Permits. This individual is Todd Adams, Hydrogeologist, Groundwater Management Section, Bureau of Water, SCDHEC.

Response: CH2M-Jones has been in contact with Mr. Adams regarding our proposed activities since September, 2000. Mr. Adams has been provided HRC background information and a copy of the CMS Work Plan. He has provided assistance in the preparation of the Underground Injection Control Permit Application, being submitted under separate cover.

6. The Periodic Performance Monitoring plan laid out in Tables 5-1 and 5-2 illustrates dissimilar sampling parameters for injection well clusters near GW012 and GW013. Due to the fact that both clusters were laid out with a similar purpose and that this is a pilot study designed to provide information on future remedial action, the Department recommends consistent sampling parameters for both clusters.

Response: Table 5-2 contains a typographical error. It is our intent to analyze Periodic Performance Verification samples from wells A039GW013, A039GW13I and A039GW13D for dissolved gases and volatile organic acids in addition to the other parameters listed. The Table 5-2 of the Work Plan table will be corrected.

7. Although it is stated in Section 5.3 that the "new wells will be used to fill data gaps in downgradient water quality in the plume interior" and "wells will be

installed, developed, and sampled for aquifer geochemical baseline and VOC parameters prior to initiating the actual HRC injections," no sampling schedule other than that for new wells GW24I and 24D has been proposed. Please propose a sampling schedule including analytical parameters for the new wells.

Response: As discussed in lines 18-22 of Section 5.3 of the CMS Work Plan, four of the six new wells (GW25I, GW25D, GW26I and GW26D) will only be used to address water quality and potentiometric surface data gaps in the interior of the plume. These new wells are not close enough to the HRC Pilot Test sites to be useful in monitoring HRC effectiveness, and so will not be sampled at the same frequency as new wells GW24I and GW24D.

The text in lines 18-22 of Work Plan Section 5.3 will be revised as follows: " Two of the 6 new wells designated, A039GW24I and A039GW 24D will be installed to monitor HRC effectiveness near well cluster A039GW23. The four remaining new wells (GW25I, GW25D, GW26I and GW26D) are being installed to provide additional water quality, water level, and stratigraphic data in the interior of the plume area, and are not intended to monitor HRC effectiveness during the pilot test."

In addition, Work Plan Table 5-4 will be added to show the proposed sampling frequencies and analytical scope for new wells GW25I, GW25D, GW26I and GW26D.

8. Please clarify the anticipated zone of influence of the HRC over time. Also, please include a brief description of the particular geochemical/chemical changes that indicate the HRC system is "active" and the parameters that show it is "working."

Response: The expected zone of influence of the HRC is based upon known groundwater flow rates, dissolved VOC distribution, HRC consumption rates and environmental persistence. Based upon previous studies, site information and the Regenesis proposal, the HRC will degrade within approximately 1 year, even if no microbes are present.

The approximate annual groundwater horizontal flow rate of 15 feet per year is a conservative approximation of the maximum extent of HRC influence, since it ignores contaminant retardation and biodegradation. Supplemental technical information discussing changes in aquifer geochemistry during HRC-enhanced bioremediation are available in the two Battelle "Conference Papers" books previously provided to SCDHEC. A summary will be added as an Appendix to the Work Plan.

From: Mansour N. Malik

Hazardous Waste Section, Division of Hydrogeology, Bureau of Land and Waste Management

Date: 01/23/2001

Re: Navbase Charleston (CNC)
Charleston, South Carolina
SC 1 70 022 560

Corrective Measures Study Work Plan , Enhanced In Situ Biodegradation Pilot Test for SWMU 39, Zone A, Revision 0, Dated October, 2000

The Document referenced above has been reviewed with respect to the requirement of R.61-79 of the South Carolina Hazardous Waste Management Regulations, The Environmental Protection Agency's (EPA) RCRA Facility Assessment Guidance Document dated October 1988, and the revised EPA Region IV Environmental Compliance Branch Standard Operating Procedures and Quality Assurance Manual (SOP/QAM) dated May 1996, the CNAV Final Comprehensive Sampling and Analysis Plan dated 30 August 1994, CERCLA 120(h) as amended.

Based on the results of the current review, the Department approves the CMS Work Plan pending resolution of the following comments:

Comments:

1. *Section* 2.1, Line 9: For developing a pattern to show the pace with which the natural attenuation is taking place, the Department recommends that this CMS-WP should include of a sequence of timed -isopach geochemical contour maps to support the natural biodegradation process and to link that with how efficiently will the HRC enhance the process. This approach also should include a current count of the present microbes in relation with the natural biodegradation process.

Response: The preparation of sequential geochemical contour maps over an elapsed time period is not possible in the Work Plan, because the geochemical data have not yet been collected. Historical information is available in the EnSafe Monitored Natural Attenuation Report, December, 1999. The feasibility of

preparing these maps for the Pilot Test report will be evaluated after these data are collected. The baseline geochemical parameters, including organic acids and gases proposed in the Work Plan are indicators of the amount of naturally occurring microbiological activity in the groundwater.

Additional technical information regarding the dechlorination microbes is available from a recent ITRC internet seminar on Natural Attenuation of Chlorinated Solvents in Groundwater (December 13, 2000), and from Regenesis' books and website. A summary will be provided as an Appendix to the Work Plan.

Section 2.2: Hydrogeology Overview and Contaminant Fate and Transport Summary. A block 3D-geologic diagram would have served to set a very clear picture of the site lithological strata. The department recommends including such a diagram in this CMS-WP especially to delineate carefully the boundaries between the lower and the upper aquifers and the predictable pathway that the HRC will follow.

Response: Generalized cross section diagrams of the Zone A geology in the east-west and north-south directions were prepared by EnSafe for the Zone A RFI, and will be added to the SWMU 39 HRC Pilot Study Work Plan.

CH2M-Jones will also evaluate the feasibility of putting existing boring log data from previously installed monitor wells and data from new wells into a 3-D spatial visualization program called EVS, which can conceptually illustrate the relationships of the various hydrogeologic units, including the permeable units into which HRC will be injected.

2. *Section 2.2 Line 29+*: From the geologic sections generated for the site so far, it is apparent that the surficial aquifer/aquifers is highly heterogeneous due to the random distribution of the clay beds. Also the boundary between the upper and the lower aquifers, as crucial as it appears for the HRC injection, is not clearly established. The aquifer testing for determining the flow velocity should take into consideration the variation in each stratum separately. Horizontal flow velocity is more likely to be greater than the vertical in this situation. The Department is concerned because of the importance of understanding the hydrogeological setting of the site in regard to the HRC injection plans. Please demonstrate control of the HRC.

Response: It is assumed that the reviewer is referring to the "shallow, intermediate and deep zones" of the water table aquifer postulated by EnSafe to occur in some parts of NAVBASE. While this shallow aquifer system has been shown to be relatively heterogeneous, available water level data indicate that the various permeable units where groundwater is encountered are interconnected, with very little vertical hydraulic head difference.

The maximum horizontal groundwater flow velocity documented in Zone A is approximately 15 feet per year or less, and the horizontal hydraulic gradients in the three "zones" are very similar. The depth to the top of the underlying Ashley Formation, which functions as the lower bounding unit for the water table aquifer, is relatively well documented by EnSafe.

A contour map showing the elevation of the top of the Ashley Formation was presented previously by EnSafe, and will be added to the Work Plan as an Appendix.

3. *Section 5.3 Monitor Well Installation*: Line 12: In pointing to a plume boundary the Department recommends that this document should show on a map the current detailed plume boundary in conjunction with the existing monitoring wells. This will give a clear picture to where the injection wells and the post injection monitoring wells should be located.

Response: The exact geometry of the dissolved phase chlorinated VOC groundwater "plume" cannot be optimally mapped with the existing monitor well network. This is, in part, why additional wells are proposed, both in the plume interior and downgradient towards the property boundary. An approximate contour line showing the downgradient limits of selected VOC concentrations in groundwater exceeding MCLs will be developed using historical data and will be added to the Work Plan- see response to Elizabeth Frady comment number 3 above.

It should also be noted that the extent of the dissolved plume "leading edge" or fringe will not affect where post-injection monitor wells should be located, since the purpose of this pilot test is to treat/impact the areas with highest VOC concentrations in the plume, not the low concentrations in the plume fringe.

4. The impact or lack of impact of the HRC on the surface water bodies, the Noisette Creek, the Cooper River and the wetland southwest of the contaminated site should be explained. The Department would like to see that included in this CMS-WP.

Response: Maximum groundwater flow velocities measured in Zone A during the RFI are less than 15 feet per year, and all proposed HRC injection locations are at substantially greater distances than 15 feet from any surface water body. HRC is a non-toxic, food-grade nutrient material. Therefore, no adverse impact to adjacent surface water bodies from HRC injection is expected.

5. *Section 5.3 Line 4+*: The Department is concerned whether using PVC will have any impact or reaction with the HRC in a VOC - contaminated area. Please clarify if that would matter in any way.

Response: The HRC liquid is food-grade, nontoxic, non-aggressive material. Because the HRC is not aggressive, negative impacts on PVC wells casing have not been observed in previous studies, and are not expected to be an issue during this pilot test.

6. *Table 5-2: Dissolved Gases:* As methane is a final byproduct from the reductive-dechlorination of the VC and the DCE, the Department recommends the periodic performance monitoring should also watch for methane as well.

Response: Agreed; as already indicated in Tables 5-1 through 5-3, methane and carbon dioxide will both be analyzed during the baseline geochemical and periodic performance monitoring programs (prior to and after HRC injection).

7. A well request is required for placement of injection of monitoring wells. These requests should be reviewed and approved by the Department prior to field implementation.

Response: A request for permission to install monitor wells and Geoprobe points was completed and submitted to Paul Bergstrand of SCDHEC on November 27, 2000. No comments from SCDHEC regarding the request have been received to date, but in a meeting with Paul Bergstrand on December 12, 2000, this work was given verbal approval.